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CONTENTS

223 Field and Laboratory Studies on Oiled Gravel Roads
By K. G. Latham, T. L. Lee, G. P. Richard, and P. J. Way

241 Jet Fuel Thermal Stability Studies by Electron Microscopy
By Robert K. Johnston and J. E. Shamblin

251 Annual Report for 1960

263 Forty-eighth Annual General Meeting

265 Obituary: James Alexander Jameson, C.B.E.

Abstracts 780–934

Book Reviews

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By K. G. LATHAM †, T. L. LES †, G. P. RICHARD †, and P. J. WAY †

SUMMARY

A method of treating gravel roads with oil has been evolved recently in Sweden and has met with great success. Field and laboratory studies have been carried out to determine whether the Swedish technique, suitably modified, could be used with advantage in other areas where the same economic problems exist of maintaining extensive gravel road systems with very limited funds. Laboratory methods were evolved to determine the effects of oil binder quality and aggregate characteristics upon such important variables as mix stability (by a modified California bearing ratio test) and binder/stone adhesion (by a static immersion test and a modified immersion wheel tracking test). The results of the laboratory studies have been correlated with field performance data from trials in Sweden, Scotland, England, and Uganda.

It is considered that the successful application elsewhere of the technique used in Sweden involving a relatively fluid binder is mainly dependent upon the existence of climatic conditions similar to those of Sweden. It also depends upon the availability of naturally densely graded and mechanically stable aggregate, responsive to the effect of adhesion agent, and not containing excessive quantities of fines or clay.

In warmer climatic areas, or where only aggregates of relatively low mechanical stability are available, more viscous binders than that used in Sweden are required.

INTRODUCTION

THIS paper presents the results of a programme of research involving both laboratory and field test work, to determine the applicability of the successful road oiling technique, now practised in Sweden, to areas outside Scandinavia.

HISTORICAL

Roads in Europe are usually associated with so-called " black-topped " surfaces, whether of the carefully designed and engineered motorway type or of the traditional type of highway, which may have been developed by many years of repeated surface dressing and upgrading of old-established gravel or dirt roads. Nevertheless, there are many regions in the world, some with a high standard of living, in which vast mileages of roads are merely gravel or " water-bound macadam." Examples of such areas include North America, Scandinavia, Africa, India, and Australia. Although these gravel roads are absolutely vital to the development and welfare of the areas involved, they have serious disadvantages. In dry weather dust formation causes considerable danger and nuisance to traffic, and also damages adjacent crops and foliage; under the impact of modern traffic, much of the gravel surface of the road is ground up and blown away. In wet weather the surface becomes muddy and hazardous. Moreover, although these roads call for constant maintenance, which is a serious financial drain, there is insufficient money available to upgrade them to " high type " pavements. Although there is as yet little information on the relative cost of operating vehicles on earth, gravel, and bituminous-surfaced roads, studies in America have suggested that provision of a black-topped surfacing can reduce road transport costs by as much as 30 per cent.[1] It is clear from the foregoing that considerable incentive has for a long time existed to improve the worst features of gravel roads, and it is perhaps not surprising that for many years now petroleum oil has been used on gravel roads as a relatively inexpensive approach to overcoming the problems mentioned above.

It is not known when petroleum oil was first used on the public highways, but it was certainly used in California some sixty years ago.[2] This development had its inception in the oilfields, where observation of the effects of traffic over stretches of road upon which oil had been spilt led to a belief that such a procedure not only overcame the dust nuisance in dry weather but also provided a smoother and firmer surface for traffic.

Until 1921 the oil used in California for road purposes was a natural crude oil[3] containing about 60 per cent of 100 penetration bitumen. As the years passed, there was a tendency to employ even heavier binders, using refinery residua containing up to 75 per cent bitumen.

* MS received 2 January 1961.

† Esso Research Ltd.

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In 1932 the State of Kansas extended its range of road oil specifications to include a binder with only 55 per cent of bitumen residue for use in cold weather.[4]

In 1932 the use of liquid bituminous road materials was widespread throughout the U.S.A. on account of the increased demand for low-cost highways, and in that year, as a result of efforts sponsored by the U.S. Bureau of Public Roads,[5] the confusion that had arisen in the nomenclature of these materials was simplified by classifying them into three groups, rapid-curing, medium-curing, and slow-curing. The first two groups were essentially cutback products, consisting of a bitumen base fluxed to the required viscosity with naphtha or heavier distillate. The third group, which are even now referred to as " road oils," were either cutback residua or straight-run products, depending upon the practice of the producer or the nature of the crude. The Asphalt Institute Specifications of the slow-curing cutbacks[6] or " road oils " are given in Table I. Although these slow-curing products are still used in the States of California, Illinois, Wisconsin, and Missouri,[7] their use has declined throughout the U.S.A., where they have been replaced by the use of binders for hot-mix materials needed to produce roads capable of bearing the increasing volume and weight of traffic.

With regard to the use of road oils in Europe, the most persistent efforts in their use have been in Sweden, where the difficulty of maintaining the

TABLE I

Cutback Specifications

	Swedish * NH cutback	Asphalt Institute slow-curing cutbacks †			
		SC.1	SC.2	SC.3	SC.4
Viscosity:					
Temperature for 500 cS, °C	40–50	(34–44)‡	(43–57)	(62–72)	(71–83)
Furol viscosity—					
50° C (122° F)	(150–340)	75–150	—	—	—
60° C (140° F)	—	—	100–200	250–500	—
82·2° C (180° F)	—	—	—	—	125–250
Distillation:					
Volume, % at—					
225° C	Nil	—	—	—	—
260° C	0·5 max	—	—	—	—
315° C	0·5–6·0	—	—	—	—
360° C (680° F)	4·0–12·0	10–30	5–25	2–15	10 max
Residue:					
Float test at 50° C (122° F)	(19–25)	20–100	25–100	50–125	60–150
Temperature for 500 cS, °C	58–68	(60–95)	(69–95)	(85–100)	(88–105)
Asphalt residue of 100 pen, %	(45 ca)	50 min	60 min	70 min	75 min

* See reference 10.
† See reference 6.
‡ Figures in brackets are calculated.

50,000 miles of gravel roads is particularly acute. Not only is there the problem of dust-laying in the summer months, but in the winter frost penetration can occur to a depth of 10 ft. Therefore, in Sweden, from 1930 onwards, repeated experiments were carried out on the treatment of gravel roads with oil, but these efforts were only partially successful.[8, 9] The oil provided an effective means of dust-laying, but it was inadequate when the requirements called for good adhesion between aggregate and binder, and maintenance costs remained high.

Fresh interest in the use of road oils was stimulated in Sweden in 1950 when effective adhesion agents became commercially available. As a result of further trials it was found that when a densely graded aggregate was mixed with a relatively fluid binder[10] (Table I) containing 1·5 per cent of stearine amine, a remarkably stable, waterproof, and self-healing surface could be achieved. These self-healing properties of the modern Swedish oil-bound gravel roads were attributed to the fact that the relatively fluid

FIG 1

OILED GRAVEL ROAD IN SWEDEN

binder used (containing around 45 per cent of 100 pen residue), whilst providing an impervious surface, did not harden to the same extent as the SC.3 and SC.4 cutbacks used in the U.S.A. (which contained over 70 per cent of 100 pen bitumen). It is of interest to note that in Sweden attempts have been made to use conventional slow-curing cutbacks, but experience there was that they led to hard surfaces which cracked and could not be reshaped with simple equipment. As a result, in Sweden the non-hardening material is now used universally, and for this reason, in this paper, products meeting the Swedish specifications have been termed " non-hardening " (NH) cutbacks.

Some idea of the extent to which the technique has been developed in Sweden can be judged by the fact that already about 1500 miles of road are being treated with non-hardening cutback each year. Some of these roads, which carry an average of 500

vehicles a day in the summer months, have already provided good riding quality for five years with only nominal attention. A typical oiled gravel road, which has given two years service to up to 500 vehicles a day, is illustrated in Fig 1.

OBJECTIVES

It has been indicated already that the technique of road oiling has been widely practised for many years, and it is therefore not surprising that the method of mixing and laying the oiled gravel varies in different locations. The method used in Sweden involves premixing of the aggregate (which can be very cold even in midsummer), NH cutback; and adhesion agent. The plant for this is normally stationary and located strategically to serve the area involved. The stockpiles of aggregate are built up throughout the year, but are mixed only during the laying season from spring to autumn. This technique involves the use of a fluid binder and an adhesion agent, since otherwise adequate mixing with the cold, wet aggregate would be difficult to achieve.

In Wisconsin, on the other hand, the normal technique is to make a road-mix using surface-dry aggregates and binder without adhesion agent, under conditions such that the mixing temperature is at least 50° F, and thus the use of a more viscous product than that used in Sweden is possible.

Because of the apparent success of the two quite different techniques, it seemed desirable to determine whether there were any significant advantages to be gained from either. In consequence, a programme of work has been completed in the authors' laboratories to investigate mix design criteria and to evaluate the laboratory findings under service conditions. An additional aim of the programme was to determine the applicability of the technique of road oiling to areas outside those in which it is currently used.

EXPERIMENTAL

1. Laboratory Investigation

(a) *Materials Used*

(i) *Petroleum Products*

One of the major points of advantage claimed in Sweden for the use of NH cutback is the ability to rework, even after several years, a surface following frost damage. It has been stated in Sweden that this property does not apply to any of the Asphalt Institute SC (slow-curing) products, the specifications[6] of which are compared in Table I. In view of this, in the present programme products meeting the Swedish NH as well as certain Asphalt Institute SC and MC (medium-curing) cutback specifications[6] were evaluated, brief inspection data being given in Tables II and III.

Table II

Non-hardening Cutbacks used in Laboratory and Field Studies

	Specification		Test binder code				
			A	B	C	D	E
Viscosity:							
Temperature for 500 cS, °C	40·0	50·0	45·0	44·5	44·5	47·0	45·0
Distillation:							
Vol % at—							
225° C	—	Nil	Nil	—	—	—	—
260° C	—	0·5	0·5	Nil	—	Nil	Nil
315° C	0·5	6·0	1·5	1·0	Nil	2·5	0·5
360° C	4·0	12·0	11·5	9·0	9·0	8·0	8·5
Viscosity of 360° C + residue:							
For 500 cS, °C	58	68	64	68	60	73	69

Since it was believed that the origin and composition of the NH product might be important, binders from five different locations were included.

Table III

Slow-curing and Medium-curing Cutbacks used in Laboratory and Field Studies (Main Properties)

	ASTM method	SC.2		SC.3		SC.4		MC.4	
		Specification	Test binder F	Specification	Test binder G	Specification	Test binder H	Specification	Test binder J
Viscosity Furol:	D.88								
At 140° F sec		100–200	130	250–500	480	—	—	—	—
At 180° F sec		—	—	—	—	125–250	165	125–250	160
Distillation (total distillate to 680° F, %)	D.402	5–25	19	2–15	11	10 max	5	—	—
Distillate (% of total distillate to 680° F):									
To 437° F		—	—	—	—	—	—	Nil	Nil
To 500° F		—	—	—	—	—	—	30 max	14
To 600° F		—	—	—	—	—	—	40–80	69
Float test on residue at 122° F, sec	D.139	25–100	80	50–125	85	60–150	80	—	—
Asphalt residue of 100 pen, %	D.243	60+	60	70+	71	75+	72	—	—
Penetration of residue, 100 g, 25° C, 5 sec	D.5	—	—	—	—	—	—	120–300	175

TABLE IV

Grading Analyses of Aggregates used in Field and Laboratory Trials

Aggregate Number	Description	Grading	Wt % passing BS sieves											Field test site number (Table IX)
			1 inch	¾ inch	½ inch	⅜ inch	¼ inch	No. 8	No. 14	No. 25	No. 52	No. 100	No. 200	
1	Scottish moraine gravel	*a*	100	97	90	72	53	40	—	18	11	9	8	1
2	Crushed Skye granite	*b*	100	87	56	33	19	17	—	9	6	4	2·5	2
3 (*a*)	Northants flint/ironstone gravel	*c*	100	97	94	62	44	38	32	27	14	7	6	3
3 (*b*)														4
4	Berkshire flint gravel	*d*	100	100	83	50	38	32	29	24	7	5	4	4
5	Swedish moraine gravel as used in Sweden	*e*	100	100	86	59	41	32	26	17	11	7	6	5
6	Swedish moraine "high fines" gravel	*f*	100	100	74	53	41	35	28	21	17	14	12	
7	Swedish moraine "low fines" gravel	*g*	100	100	95	66	41	30	20	12	6	3	Nil	
8	Crushed Leicestershire granite	*h*	100	100	100	74	55	—	25	—	—	8	5·5	3
9	Lateritic gravel	*j*	100	97	80	47	28	24	20	18	16	15	12	6
10	Lateritic gravel	*k*	100	98	94	77	63	58	54	49	44	40	37	7
11	Lateritic gravel	*l*	100	98	93	63	37	32	26	25	24	22	20	
11	Lateritic gravel	*m*	100	94	86	53	26	19	15	14	13	12	11	
12	Quartzitic gravel	*n*	100	100	100	77	60	52	45	40	34	28	23	7
13	Quartzitic gravel	*o*	100	98	92	70	42	29	14	10	8	5	2·5	
Limits of Swedish recommended grading:[*]														
Maximum			—	100	93	72	53	42	33	24	16	11	9	
Minimum			—	100	73	47	30	22	16	10	7	5	3	

[*] See reference 10.

(ii) *Aggregates*

Since the applicability of the technique in widely different geographical locations was under examination, aggregates from a number of sources were examined. The sieve analyses and description of these materials, which were of widely different geological types, are provided in Table IV.

(iii) *Adhesion Agent*

Throughout the work stearine amine was used; the approximate analysis and composition, which was provided by the suppliers, is given in Table V.

TABLE V

Stearine Amine

Stearine amine is a long chain primary amine derived from fatty acids via reduction of the corresponding nitrile.

The material used in the present investigation was obtained from Liljeholmens Stearinfabrics AB, Stockholm, who have provided the following information:

Formula: RNH_2 where R is straight chain hydrocarbon consisting of:

Approx 5% saturated C_{14}
Approx 46% saturated C_{16}
Approx 41% saturated C_{18}
Approx 8% unsaturated C_{16} and C_{18}

Analytical data:

Primary amines with the formula RNH_2	91–94%
Secondary amines	3–5%
Nitriles and hydrocarbons	3%
Iodine value	8

(b) *Laboratory Investigations*

In the laboratory, two major topics have been investigated, adhesion and the mechanical stability of various aggregate–binder combinations.

(i) *Adhesion*

In Sweden adhesion agents are considered to be essential for a successful surface, but they are not used in Wisconsin. Both the available aggregates and the choice of binder probably account for this difference. In Wisconsin, the aggregate often contains a fair proportion of limestone. This will assist adhesion between the binder and the stone, and at the same time will tend to reduce the effectiveness of amine adhesion agents. On the other hand, in Sweden the stone is granite, contains little or no limestone, possesses poor natural adhesion, but responds very well to the addition of an amine adhesion agent. In Wisconsin the tendency is to use heavy cutbacks as binder, while in Sweden more fluid binders are used. Since in general the more viscous binders are less prone to retract from stone under the influence of water, it follows that in Wisconsin the use of an adhesion agent is less necessary than in Sweden. Moreover, the climate and method of operation in Sweden require that an "active" adhesion agent be present to displace water from the cold, wet aggregates used, whereas in Wisconsin the hot summers permit the aggregate to be air dried, and only "passive" adhesion is called for. Active adhesion is the effect of enabling a binder to displace water from stone and thus coat the latter adequately, whereas passive adhesion is the effect of a binder in resisting the displacing action of water with time. Generally speaking, an active adhesion agent promotes good passive adhesion.

From the above discussion it seems that the basically different approach in Sweden, that of using relatively fluid binders containing an adhesion agent, has been evolved to suit local conditions with respect to climate and gravel supplies.

Whilst experience with and without adhesion agent has been satisfactory in Sweden and Wisconsin respectively, it appeared that for a satisfactory mix to be designed, a quantitative laboratory method was required to assess the adhesivity of any binder to any stone. Accordingly, the initial target of laboratory work in the authors' laboratories was the development of a simple screening test for this purpose.

Several different approaches were employed, including dye adsorption on stone which had been mixed with binder and then immersed in water; measurement of heat of wetting was also considered, as were a variety of other possibilities. However, the complexity of the equipment or techniques involved outweighed the possible advantage which could be gained in accuracy. Therefore the method finally adopted was a simple immersion test.

This test was carried out by mixing NH cutback containing various quantities of adhesion agent with the test aggregate, and finding the concentration of adhesion agent which just prevented immediate visible stripping when the freshly mixed material was immersed in distilled water at 65° F. It was found that this method gave such reliable and repeatable results that it was used to determine:

(1) Effect of surface area (fines content) on the requirement of adhesion agent.

(2) Variation of amine requirement with aggregate moisture content.

(3) Variation of amine requirement with binder content of mix.

In order to reduce sampling errors and also to compare different aggregates on the same basis, each type of stone was carefully sieved and reconstituted to meet the mean Swedish recommended grading (Table IV).

(1) *Effect of Surface Area.* The investigation of the effect of surface area (as indicated by fines content) revealed that there was a linear relationship between the amine content needed to prevent stripping and the percentage of added fines in the mix. The slope of the line varied with different aggregates, as shown in Fig 2. It is considered that the slope of the line represents the response of the aggregate fines to adhesion agent, while the intercept at zero fines is a measure of the response of the base aggregate (*i.e.* the material existing in sizes retained on 200-mesh screens and above). An aggregate containing some limestone in its fine material, such as gravel No. 3 (*b*), has a poor response to adhesion agent, and if the material passing a 200-mesh screen greatly exceeds 6 per cent an uneconomically high concentration of adhesion agent is required to prevent stripping. The difference in the reaction of this aggregate to amine, as compared with that of gravel No. 3 (*a*), is remarkable, since both samples were taken from different parts of the same gravel pit. This emphasizes the need to maintain careful control to ensure that an adequate amount of amine is used.

(2) *Effect of Moisture Content of Aggregate.* It is well known that moisture has a substantial effect on the ease with which gravel can be coated. Therefore, since wet aggregate must frequently be used, it was decided to determine the effect of the moisture content of the aggregate on the amount of amine required to achieve proper coating.

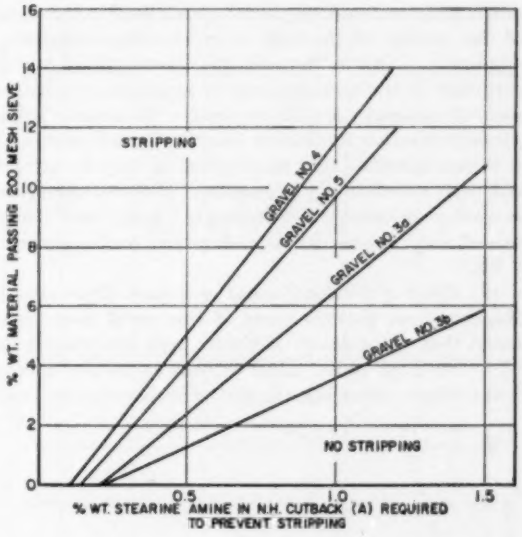
% WT. MATERIAL PASSING 200 MESH SIEVE
STRIPPING
NO STRIPPING
GRAVEL NO 4
GRAVEL NO 5
GRAVEL NO 3a
GRAVEL NO 3b
% WT. STEARINE AMINE IN N.H. CUTBACK (A) REQUIRED TO PREVENT STRIPPING

FIG 2

IMMERSION TESTS ON VARIOUS AGGREGATES

Effect of aggregate fines content on stearine amine requirement

Aggregate grading *c*
Aggregate moisture content 5 wt %
Aggregate binder content 3·5 wt %

Fig 3 presents a curve typical of the results obtained, and indicates that little or no adhesion agent is required to prevent immediate stripping after a mix made with dry stone No. 5 has been immersed in water. However, other adhesion tests, such as the immersion wheel tracking test, show that a stone whose natural adhesion is poor requires an adhesion agent to be incorporated into the binder, even if a mix is made with dry stone. It is believed that Fig 3 merely illustrates the fact that an amine adhesion agent can facilitate the thorough coating of wet aggregate with binder so that it will resist the immediate stripping action of water. It does not alter the fact that, even using dry aggregates, the use of an adhesion agent may be called for to exert a long-term or " passive adhesion " effect. The " active " effect of the amine in displacing water from wet stone has application in pre-mix operations, where the binder is accurately proportioned; relatively high levels of water in the aggregate can thereby be

tolerated. Even so, a much more even mix is invariably obtained if the mixing operation is carried out using an aggregate which is essentially surface-dry.

Whilst in pre-mix operations the coating of somewhat wet stone has not proved to be a disadvantage, it has been found essential in road-mix work, where much reliance must be placed on a visual assessment of the quality of the mix, to work with surface-dry aggregate. This is because the uncertainties which can exist in the measurement of aggregate quantities make it necessary for the foreman to be able to judge visually whether the binder quantity is sufficient, and it is thus essential that mixing should only be carried out with a surface-dry aggregate. If a wet aggregate is used, a material which in fact is " lean " and badly mixed may appear to be well-mixed and somewhat " fat."

(3) *Effect of Binder Content on Amine Requirement.* Reports from various parts of the world have indicated that the amount of binder used can vary from 3½ to over 5 per cent. Since laboratory measurements had indicated that the amount of amine required was

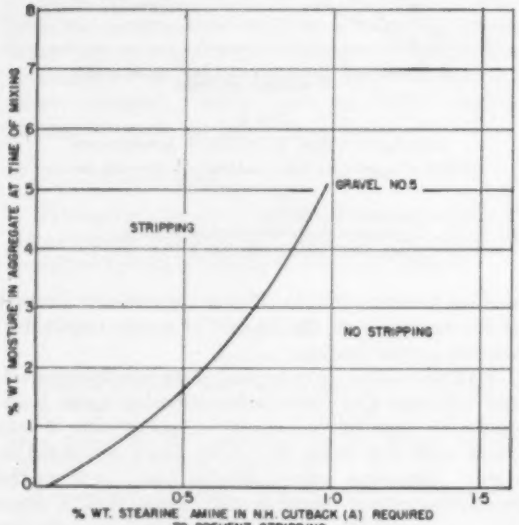

FIG 3

IMMERSION TESTS ON SWEDISH MORAINIC GRAVEL (NO. 5)

Effect of aggregate moisture content on stearine amine requirement

Aggregate grading *c*
Aggregate binder content 3·5 wt %
Aggregate fines content 9·0 wt %

related to the relative surface area of the stone, it was decided to check whether, at high binder contents, a lower percentage of amine to oil could be used.

Fig 4 shows that this is the case. However, despite this finding, it will be shown later that this phenomenon has little practical significance with a given stone/binder combination because of the overriding problems of mechanical stability.

(ii) *Mechanical Stability*

It has been shown that aggregates vary considerably in their response to amine adhesion agent and

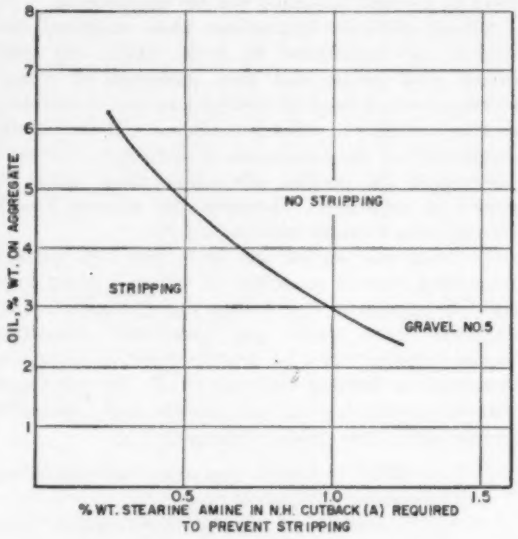

FIG 4

IMMERSION TESTS ON SWEDISH MORAINIC GRAVEL (NO. 5)

Effect of NH cutback content on stearine amine requirement

Aggregate grading *c*
Aggregate moisture content 5 wt %
Aggregate fines content 5 wt %

binder, and it was known that substantial variations can occur in the mechanical stability of gravels within the same grading limits. Therefore, means were required to measure the mechanical stability of gravel/binder mixes to assess their possible utility as road surfacing materials.

(1) *Static Test.* At least three laboratory tests are available for this purpose. These are the Hveem Stabilometer,[11] the shear box,[12] and the California Bearing Ratio (CBR) apparatus.[13] In Sweden the shear box was used successfully by Hallberg,[12] but such equipment was not available to the authors, and they therefore used a modified CBR equipment for their work. The modification involved sample preparation in a Marshall[14] mould (instead of the standard one), and the penetration plunger was scaled down to suit this size of mould. Before testing, the density of the samples was determined and the apparent voids contents calculated from the bulk specific gravity of the aggregate.

The data obtained on five aggregate/binder combinations are given in Table VI, which also provides

the results of modified CBR tests in comparison with field test observations of actual road performance.

TABLE VI

Results of Modified California Bearing Ratio Tests

Binder: NH cutback
Binder content: 3·5% by weight

Aggregate number	Grading (see Table IV)	Apparent voids, vol %	Load at 0·1 inch penetration, psi	Road carpet stability	Field test site number (Table IX)
2	*b*	18·0	2559	Satisfactory	2
3	*c*	3·7	4060	Satisfactory	3, 4
4	*d*	7·1	1454	Unstable	4
5	*e*	8·7	3330	Satisfactory	5
7	*g*	14·4	2370	Not known	

It is noteworthy that the three compositions which had CBR values above 2500 were satisfactory in the field. Unfortunately, no field data are available on the aggregate No. 7 system. The aggregate No. 4 mix had a very low modified CBR value and was notably unstable on the road.

To determine the extent to which small differences in grading could account for the differences found,

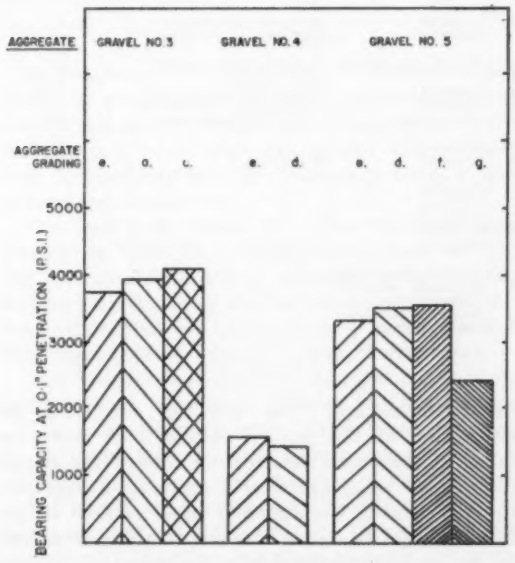

FIG 5

EFFECT OF AGGREGATE TYPE AND GRADING ON BEARING CAPACITY BY MODIFIED CBR TEST

Binder NH cutback (A)
Binder content 3·5 wt %

tests were carried out on aggregates prepared to a number of different gradings. The results shown in Fig 5 indicate that the nature of the stone had a greater influence on stability than small variations in grading, although the use of a rather " open grading," such as grading " g," caused a considerable loss in stability.

The effect of binder content on stability is illustrated in Fig 6. Aggregates 3 and 5 gave well defined peaks at a binder content of 3·5 per cent, but the poor

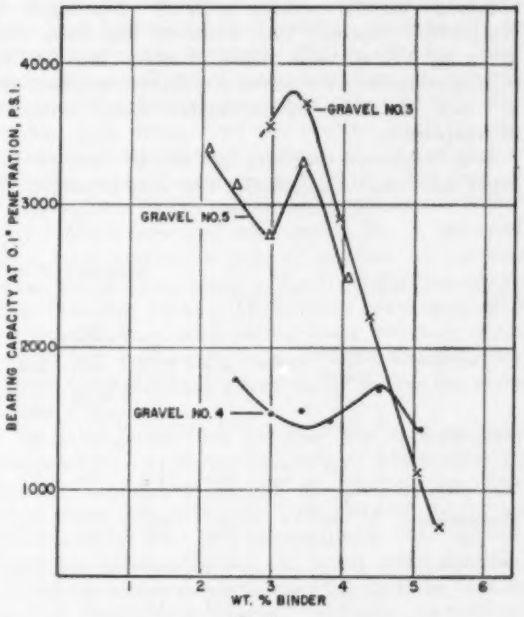

FIG 6

RESULTS OF MODIFIED CBR TESTS USING VARIOUS GRAVELS

quality No. 4 gravel showed little dependence on this variable.

Finally, the effect of binder viscosity on stability was examined by this method. It appears from Table VII that when mixes containing either NH or

TABLE VII

Effect of Binder Viscosity and Mixing Temperature on Results of Modified CBR Test

Aggregate	Binder	Mixing and compaction temperature, °F	Binder content of mix, wt %	Apparent voids, vol %	Load, psi at 0·1 inch penetration
Northants Gravel No. 3 (*b*) (Grading *e*)	NH cutback A	65	3·5	5·2	3750
		65	4·5	1·3	2260
	SC.3 cutback G	65	3·5	7·3	2340
		65	4·5	3·2	1530
		110*	3·5	6·7	3870
		110	4·5	4·0	2570
		130	3·5	6·0	4240

* At 110° F SC.3 has the same viscosity as NH cutback at 65° F.

SC.3 cutback were compacted at the same temperature the degree of compaction (as measured by voids content), when using the more viscous cutback SC.3, was lower than when using NH cutback and stability

was lower. In the field it has been found that stability of mixes compacted at the same temperature is greater with binders of greater viscosity. At 110° F SC.3 has nearly the same viscosity as NH cutback at ambient temperatures (65° F). Laboratory compaction of SC.3 mixes at this temperature resulted in measured stabilities equal to, or better than, those obtained with NH cutback at 65° F. The degree of compaction obtained was, however, less than that given by NH cutback mixes. Further increases in mixing temperature resulted in definite improvements in " mix " stability, but no further change in degree of compaction.

It is concluded that this test can be used for the rapid screening of aggregate, but that it cannot be used to compare the effect of using binders of differing viscosity. The test has also shown that stone surface-texture and shape are more important than small variations in aggregate grading in the determination of stability.

(2) *Dynamic Test.* Although the use of the modified CBR test afforded considerable information on the relative stability of gravel/binder mixes, it could not be expected to predict the combined effects of water and rolling load on the surfacing material. Since these factors are of considerable importance to any road engineer, it was apparent that a further test was required which could be used for these purposes. The immersion wheel tracking test developed by the British Road Research Laboratory (RRL) was therefore adapted for dynamic testing of road oil/aggregate mixes.[15] In this test method a sample is compacted in a tray to simulate a road surface, and is subjected, whilst immersed in water, to the reciprocating action of a wheel load of 40 lb. This method has given good correlation with road performance when used by the authors to test conventional hot-mixed materials, and it was decided to test the procedure for use with oiled gravel.

For this work, the mixing procedure specified by the Road Research Laboratory was modified, mixing and rolling being carried out at room temperature, with binder alone preheated to 90° C. The sample was then allowed to stand at room temperature for 24 hours before testing and, finally, the test was carried out at 25° C, instead of 40° C normally used in the RRL method. The test was run until disintegration of the surface occurred. A note was taken of the initial deformation rate of the sample (this figure being taken as a measure of aggregate stability) and of the apparent cause of final failure. In most cases the latter was due to adhesion failure, the binder being stripped from the stone, but in some cases, where an unsuitable aggregate was used, the surfaces disintegrated solely as a result of mechanical action.

Typical results obtained from the test are shown in Table VIII. Mixes made with NH cutback and Swedish gravel appeared to have good mechanical stability as measured by the initial compaction rate, and poor adhesion quality in the absence of adhesion agent. They responded very well to the use of

TABLE VIII

Immersion Wheel Tracking Test at 25° C

Aggregate	Aggregate number	Grading	Cutback	% Binder in mix	% Amine adhesion agent in binder	Wheel tracker			Road performance	Field test site number (Table IX)
						Initial compaction rate, cm/hr	Failure time, hr	Cause of failure		
Swedish gravel	5	*e*	NH	3·5	Nil	0·23	1·25	Stripping	Unsatisfactory — poor adhesion	Swedish experience generally
	5	*e*	NH	3·5	1·5	0·23	13·0	Stripping	Good	5
	5	*e*	SC.3	4·5	Nil	0·17	4·0	Stripping	Good	5
	5	*e*	SC.3	4·5	1·5	0·17	>15	Stripping	Good	5
Northants gravel	3 (a)	*e*	NH	3·5	1·5	0·17	1·6	Stripping	Mediocre—poor adhesion	4
	3 (b)	*e*	NH	3·5	2·0	0·17	5·7	Stripping	Mediocre—poor adhesion	4
Berkshire gravel	4	*e*	NH	3·5	1·5	Very rapid	<0·25	Mechanical instability	Unsatisfactory — mechanically unstable	4
	4	*e*	SC.3	4·5	Nil	0·7	3·0	Stripping	Satisfactory on lightly trafficked road; unstable for use with heavier traffic	4
	4	*e*	SC.3	4·5	1·5	0·5	>10	Stripping		4
Skye granite	2	*b*	NH	3·5	Nil	0·57	0·7	Stripping		
	2	*b*	NH	3·5	1·5	0·4	>10	Stripping	Satisfactory	2
Kampala lateritic gravel	11	*m*	NH	3·5	Nil	—	2·5	Stripping		
	11	*m*	NH	3·5	1·5	—	4·5	Stripping		
	11	*m*	NH	4·5	1·5	—	4·75	Stripping		
	11	*m*	SC.4	4·5	Nil	—	6·25	Stripping		
	11	*m*	SC.4	4·5	1·5	—	7·1	Stripping		
Kampala quartaitic gravel	13	*o*	NH	3·5	1·5	—	0·2	Mechanical instability		
	13	*o*	SC.4	4·5	Nil	—	0·5	Mechanical instability and stripping		
	13	*o*	SC.4	4·5	1·5	—	>19	Mechanical instability and stripping		

adhesion agent. When higher viscosity binder (SC.3) was used, mechanical stability was improved, and failure time due to stripping was greatly increased. Gravel No. 3 mixed with NH cutback showed up as having a good mechanical stability but a poor response to adhesion agent. The combination of gravel No. 4 and NH cutback had very low mechanical stability, the sample disintegrating before stripping took place. When a more viscous binder was used, mechanical stability was greatly improved, and the response to amine adhesion agent was good. Finally, gravel No. 2 mixed with NH cutback was shown to be relatively unstable and lacking good adhesion in the absence of amine, but again this material responded well to adhesion agent in terms of wheel tracking test failure time.

Thus it can be seen that the immersion wheel tracking test is able to show up differences in mechanical stability and adhesion quality and responds also to changes in binder viscosity. The results for gravels 3, 4, and 5 appear to be in good agreement with road experience. Although laboratory results indicate that gravel No. 2 was somewhat inferior to Swedish morainic gravel with respect to mechanical stability, it gave relatively good life in the wheel tracking machine and good field performance when stearine amine was used in the NH cutback.

2. Road Trials

No programme of work on road surfacing materials would be acceptable if the data obtained were confined to laboratory evaluations, without good evidence that the conclusions were of practical value. Therefore, concurrently with the laboratory work, a series of road tests was made.

The road tests which have been made are summarized in Table IX. It will be seen from this that the test sites were widely separated geographically, and each location was selected because it appeared to the authors that the type of surface under investigation might be used with advantage in that area.

The trials made in Scotland, Skye, and Northamptonshire were completed without the assistance of preliminary laboratory data. The failure encountered in Scotland (site 1), which was basically due to stripping, could have been predicted by the laboratory work, which emphasized the difficulty of achieving adequate coating and resistance to stripping with gravels of high water and fines content, *e.g.* gravel No. 1.

The behaviour of the road at Skye (site 2) was quite consistent with subsequent laboratory results, since the granite used (No. 2) was low in fines and moisture content and was responsive to amine.

The relatively short life of the sections at Northampton (site 3) was certainly due to the unusually heavy traffic, which consisted almost entirely of lorries carrying wet aggregate from a gravel pit. The longer life of those sections based upon crushed granite (No. 8) was associated with the greater mechanical stability and responsiveness to amine adhesion agent of this material compared with the local gravel (No. 3 (*a*)).

The tests in Berkshire (site 4) were carried out in dry, fine weather, and both the aggregates used (Nos 3 (*b*) and 4) were surface-dry. The aggregates had high and low mechanical stability respectively, as determined by the modified CBR test (Fig 6). They also had low and high response respectively to stearine amine. Two binders were used, NH and SC.3 cutbacks, both being used at various levels in the aggregate with different amounts of stearine amine. All sections based upon gravel No. 4 with NH cutback failed rapidly due to mechanical instability. Where NH cutback was used with gravel No. 3, the road gave good service for over 12 months, but showed some loss of stone due to stripping, regardless of the use of stearine amine. The sections based upon SC.3 were satisfactory with both gravels, although when gravel No. 4 was used it is doubtful whether they would have sustained heavy traffic during the early stages of their life.

In Sweden (site 5) a test road was surfaced with NH and SC.3 type binders, both of which after 12 months had shown no sign of deterioration. The oiled gravel was mixed and laid, however, during an exceptionally hot, dry summer, and the highway engineers responsible for the work were doubtful whether a binder as viscous as SC.3 could be used in normal conditions in Sweden. Although, up to date, SC.3 has proved at least as satisfactory as NH cutback, the Swedish Road Research Laboratories personnel have also expressed doubts regarding the ease of reworking the material in the event of frost or other damage under the conditions which exist in Sweden.

The final tests which it is proposed to discuss were performed in Uganda (sites 6 and 7). In preparation for this work, samples of the proposed aggregates (Nos 11 and 13, Table IV) were obtained and subjected to laboratory examination. The lateritic gravel sample (No. 11, Table IV) contained what appeared to be an excessive quantity of fines (20 per cent), but by hand working to simulate the action in the field by earth-moving equipment this figure was reduced to 11 per cent (grading *m*), and this resulting aggregate was used for laboratory examination in the wheel tracking test. The results were not very encouraging when NH cutback was used, even with stearine amine, although there were indications that a reasonably satisfactory surface could be prepared if an SC.4 cutback was used. Even with the heavier cutback, however, the performance of the mix as assessed by the modified wheel tracking test was inferior to the performance of the Swedish gravel, NH cutback + amine combination. Despite this, however, the

Table IX

Sites of Oil Gravel Field Experiments

Location	Scotland	Skye, Scotland	Northamptonshire, England	Berkshire, England	Sweden	Kampala, Uganda	Kampala, Uganda
Date	Aug 1959	Aug 1959	Dec 1958	Aug 1959	Aug 1959	Feb 1960	Feb 1960
Site No.	1	2	3	4	5	6	7
Weather	Continuous light rain, *ca* 50° F	Intermittent light rain, *ca* 50° F	Frequent rain, *ca* 40° F	Dry, *ca* 70° F	Dry, *ca* 60° F	Dry, *ca* 90° F	Dry, *ca* 90° F
Traffic	50 light vehicles/day	250 light vehicles/day	100 10-ton lorries/day	100 light vehicles/day	250 vehicles/day	100 vehicles/day	400 vehicles/day
Base	Badly rutted and pot-holed gravel road	Old macadam surface in bad condition	Badly rutted gravel road	Good gravel road	Good gravel road	Old gravel road	Old gravel road
Aggregate	Morainic gravel (No. 1) containing 7·5 wt % clay	Open-texture, crushed granite (No. 2)	Flint/iron-stone gravel (No. 3) containing *ca* 5 wt % clay / Crushed Leicester-shire granite (No. 8)	Flint/iron-stone gravel (No. 3) / Flint gravel (No. 4) containing *ca* 5 wt % clay	Morainic gravel (No. 5)	Lateritic gravel (No. 9)	Quartzitic gravel (No. 12) Lateritic gravel (No. 10)
Aggregate moisture content, wt %	*ca* 8	Surface-dry	*ca* 8 / Surface-dry	Surface-dry	*ca* 3	Surface-dry	Surface-dry
Aggregate temperature, °F	*ca* 50	*ca* 50	*ca* 40	*ca* 55	*ca* 35	*ca* 85	*ca* 85
Binder	NH cutback	NH cutback	NH cutback	NH and SC.3 cutbacks	NH cutback / SC.3 cutback	NH and MC.4 cutbacks	NH, SC.2, SC.4, MC.4, and experimental cutbacks
Binder content, wt %	3·5	3·8	3·5	3·5–4·5	3·5 / 4·5	*ca* 7·0	4·0–7·0
Stearine amine in binder, wt %	1·5	1·5	1·5	0–1·5	1·5 / 0–1·5	0	0–1·5
Mixing	Stationary pre-mixing plant	Stationary pre-mixing plant	Pre-mix in concrete mixer	Pre-mix in concrete mixer	Stationary pre-mixing plant	Road-mix	Road-mix
Laying	Spreader box	Spreader box	Hand or finisher	Hand	Spreader box	Grader	Grader
Compaction	50-cwt roller	8-ton roller	Vibratory roller	50-cwt roller	Traffic or 8-ton roller	6-ton roller	6-ton roller or rubber tired roller
Carpet depth, inch, nominal	1·5	1·5	1·5	1·5	1·5	2	2
Comments	After over 2 years the road, which began to deteriorate after 7 months due to loss of stone, is still giving good service	In spite of open texture the road is still in very good condition after over 2 years	After extremely arduous duties the flint/iron-stone gravel section began to deteriorate after about 3 months. The granite section did not begin to deteriorate for 6 months, and failed after 12 months	Rapid failure of NH cut-back/gravel No. 4 sections due to mechanical instability. NH cut-back/gravel No. 3 sections satisfactory for 12 months, but appreciable loss of stone due to stripping regardless of amount of amine used Both gravels satisfactory with SC.3 even when no amine used	All test sections satisfactory after compaction, and after 12 months all had an excellent texture	After six months service the best sections were those based on an experimental cutback with quarsitic gravel. The quartzitic sections made with SC.4 were also satisfactory, although they showed signs of crazing. The MC.4 sections had cracked badly, and those based on NH cutback and SC.2 had failed completely The sections based on lateritic gravel were completely unsatisfactory, and little evidence of any binder being present could be found after 6 months	

mixture was about as good as some of the other NH cutback mixes which had given reasonably good road performance.

The sample of quartzite (No. 13) had very poor mechanical stability when used with NH cutback, but when mixed with SC.4 cutback and amine gave very good results.

were used. The effect of amine and binder content was also examined.

Since in Uganda, as in most parts of Africa, facilities for pre-mixing binder and aggregate are not easily available, it was decided to use a road mix form of construction, as illustrated in Fig 7. The experimental sections have been in place only for somewhat

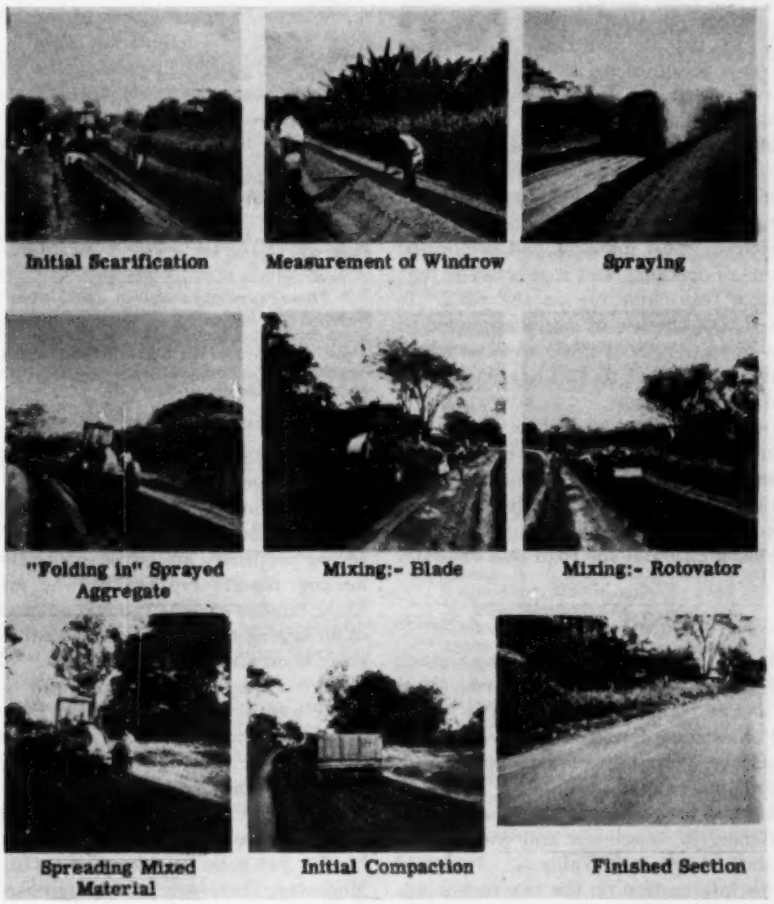

FIG 7

STAGES IN OILED GRAVEL ROAD SURFACING IN UGANDA

It transpired that the gradings of the preliminary samples bore little resemblance to those of two of the three aggregates actually used in Uganda, in spite of efforts to reduce the fines content of the latter materials by turning with a mechanical grader.

One of the main objectives of the Uganda trial was to determine the significance of binder viscosity under tropical conditions. Therefore, in the tests, which involved 20 test sections, each 40 yards long, six binders varying in viscosity from SC.2 to SC.4 grades

less than one year, and no very firm conclusions can yet be drawn regarding the results of the trial. It can be said, however, that no success was achieved with lateritic gravel at either sites 6 or 7, and rapid failure occurred whichever of the binders were used.

When the quartzitic material, gravel No. 12, was used the results were more encouraging, although it was soon evident that the less viscous binders used (SC.2 and NH cutback) were quite unsuitable. These required a very high application rate to avoid a lean

mix, lacking in cohesion; a very small increase in binder content over the optimum led to fattening in the wheel tracks, whilst the edges of the road remained dry and poorly compacted. After six months' service, surfaces laid with these materials had failed completely. The faster-curing material, MC.4, at first appeared promising, a very good surface being obtained initially. No difficulty was experienced in estimating the correct quantity of binder to use. However, the surface obtained appeared to lack flexibility, early in its life considerable cracking occurred, and over a period of six months quite large crazed areas developed in the centre of the road.

The slower-curing binder, SC.4, after six months had given considerably better service than MC.4, but here again some cracking was experienced. The most promising material investigated was an experimental product formulated to provide self-healing and non-hardening properties. This material had performed well, with no signs of cracking, and it is believed that it should possess a reasonable life on the road. It has been observed that the use of amine appeared to have little effect upon the life of those sections where it was used, presumably due to the relatively high fines contents of the aggregates.

It should be noted that the conditions of the test were quite arduous. The roads were very narrow, and one of them carried about 400 vehicles/day. In addition, the road was surfaced immediately before the rainy season, during which time the rainfall was sometimes 2 inches a day and the road was virtually under water.

COSTS

When selecting the technique for surfacing a given road, numerous factors have to be considered; these include such items as traffic density, climatic conditions, the state of existing foundations, cost of road materials and haulage, availability of equipment, and, above all, the amount of funds available.

As an indication of the way in which the costs of oiled-gravel surfacing in Wisconsin and Sweden are made up, some data are given in Table X. It should be noted that this information on the two techniques is based upon material and labour costs prevailing in two different continents.

DISCUSSION AND CONCLUSIONS

It is considered that the studies outlined in this paper, together with the relevant historical information, have adequately answered the questions that arose from the recent developments in Sweden.

Briefly, the Swedish technique differs from the more established methods used in the U.S.A., in that a more fluid "road-oil" is used. The difficulties that might be encountered from using such a fluid binder are avoided by using a densely graded aggregate, and incorporating in the binder an appreciable quantity of adhesion agent.

TABLE X

Costs

(Road 1 mile long × 20 ft wide)

	Wisconsin	Sweden
Material quantities:		
Nominal carpet thickness, inches	2	1·5
Binder	SC.3, SC.4	NH
Aggregate, long tons	1100	950
Aggregate, cu yd	870	765
Binder, % wt aggregate	4·3	3·5
Price of materials:		
Binder, shillings/gal	0·55	1·0/1·5
Aggregate, shillings/cu yd	8·8	8·3
Price of stearine amine, £/LT		300
Cost of construction, £:		
Binder	340	395/595
Aggregate	380	320
Stearine amine	Nil	120
Mixing/laying	285*	490
Total, £	1005	1325/1525
Cost, shillings/sq yd	1·7	2·25/2·5

* These operating costs seem somewhat low compared with those in Sweden. The Wisconsin figures are, however, based upon data after many years experience throughout the state. Those in Sweden are derived from limited experience of a largely experimental nature but with a daily plant production of 200 tons of mix.

Local climatic conditions in Sweden demand a relatively fluid binder for ease of mixing, and its curing properties are governed by the need for a self-healing, readily reworkable, and impervious carpet. Fluid binders such as the NH cutback call for the use of an aggregate of good mechanical stability, of which there is an abundance in Sweden. Moreover, the use of such binders, and the need for mixing with cold, often wet aggregates, call for the use of adhesion agents and in this respect the Swedish engineers are fortunate in that the available aggregate responds readily to amine type additives. It has been shown that a mechanically unstable aggregate cannot produce a stable carpet when NH cutback is used as binder, but calls for a heavier cutback, such as SC.3. Moreover, there are many aggregates which do not respond particularly well to the use of adhesion agent, but there are indications that "passive adhesion" can be improved by the use of the more viscous type of binder. It can be concluded that the method evolved in Sweden for treating gravel roads has resulted from the successful adaptation of available materials to meet local circumstances and requirements.

It is further concluded that the Swedish technique of using a binder as fluid as NH cutback cannot be universally applied to the low-cost surfacing of gravel roads without careful consideration of the climatic conditions which are likely to be experienced, and the type of aggregate locally available. Whilst operations

similar to those in Sweden might be successfully carried out in other areas where similar conditions pertain, such as Finland, Norway, Northern Scotland, and Ireland, this would depend upon ready availability of suitable aggregate, *i.e.* densely graded, responsive to active adhesion agents, and not containing excessive quantities of clay.

In an area where the climate differs greatly from that in Sweden, namely, Uganda, it was found that the NH cutback used in Sweden was unsuitable for road-oiling. The work in Uganda confirmed that better results should be achieved by using the heaviest binder consistent with ease of mixing, although the hardening properties of the binder are of considerable importance. The tests in Uganda also suggested that it is unlikely that a satisfactory surface can be made when road oils are mixed with lateritic gravel.

Some simple laboratory tests have been evolved for the screening of aggregate/binder mixes, both from the point of view of adhesion quality and of mechanical stability.

The simple immersion test requires no specialized apparatus and can be used quickly and conveniently to evaluate the reaction of a given aggregate to adhesion agents.

The modified immersion wheel tracking procedure tests both the adhesive and the mechanical properties of an aggregate/binder mix. It is sensitive to changes in binder viscosity and appears to give results consistent with those obtained in the field. It should be possible, using this test, to decide whether a given mix is likely to yield a durable surface.

The modified CBR test has been found useful for the rapid screening of aggregates, but the anomalous results obtained using binders of varying viscosity have limited its usefulness.

These tests have been shown, within certain limitations, to line up fairly well with field experience, and it is believed that they can be of considerable use for the purpose. Nevertheless, some experience is required to interpret the results of these tests, and blind acceptance of them without some knowledge of the conditions existing at the site where mixing and laying work is to be carried out may lead to difficulties.

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DISCUSSION

A. W. Jarman (Shell-Mex and B.P. Ltd): Those of us who are interested in bitumen, those of us who are interested in roads, and some of us who take an interest in both, feel very indebted to the four authors for having ventilated a subject which has tended to become somewhat confused in the minds of road engineers, who, due to the financial stringency under which they have to operate, would naturally be attracted by road surfacing processes which might appear cheaper than those conventionally used.

The authors of the present paper have therefore been helpful in bringing out, quite forcibly, that the Swedish process was devised by Swedish engineers specifically for Swedish conditions, and it does not necessarily follow that it would be equally suitable elsewhere.

There appeared to be three main factors which have contributed to the development of this process. In Sweden there are large areas of country where the roads have not been brought up to the standard that we enjoy in the U.K. Secondly, the traffic conditions in those areas are appreciably less than those with which we have to contend, but are increasing, and therefore call for some improvement in the road surfacing. Thirdly, they are short of money, which is a very common situation. Additionally, and this point needs emphasis, Sweden has a climate which involves periods of heavy frost with consequent disruption of the existing low-standard road surfacings. If it were not for the frost problem it is doubtful whether the present system of surfacing would have been devised.

The treatment of water-bound macadam roads has interested engineers in various parts of the world for many years. In the U.K. surface treatment with bitumen has frequently been sufficient to enable the minor roads to contend with modern traffic, although it is realized that when designing a completely new road a different technique might be employed. In Sweden the frost hazard requires special consideration, and on that account it appears that engineers there are prepared to accept a form of surfacing which, initially, is of lower stability than would be acceptable in Britain because this is compensated by the extended workability of the oiled gravel which permits re-shaping of the surface when disrupted by frost.

On p. 224 reference is made to a "non-hardening cutback," and I suggest that this is something of a misnomer, because the figures show that there is an appreciable increase in viscosity on heating which is not in fact very different for that shown for some of the American slow-curing cutbacks.

On p. 225 the storage of the gravel before coating is mentioned, but it was not until Mr Les made his opening remarks that it was stated that the material is also stored for long periods, and this has a bearing on the need for a low viscosity binder.

On p. 227 there is a reference to the well-known total water immersion test, the exact correlation of which with road performance has concerned road technologists for many years. It would be of interest to hear from the authors their interpretation of the phenomenon of immediate stripping, as the test is normally allowed to run for some hours before recording the result.

It has also emerged that the test result may be significantly influenced by the pH value of the water. It is also stated that no stripping occurred if the stone were pre-dried before mixing; this conflicts with the views currently held in the U.K. on coated macadam.

On pp. 228 and 229 the authors have introduced a unit for the measurement of stability which is based upon the CBR system but bears a rather striking resemblance in the magnitude of the figures to the Marshall stability results which have recently been developed for asphalt surfacings. It is necessary to avoid confusion occurring between these tests.

The relatively small amount of binder used in the oiled gravel system compared with gravel macadam, as manufactured in the U.K., suggests that there is a somewhat different mechanism, and it seems probable that in the Swedish system much greater reliance is placed upon the mechanical stability of the aggregate, as distinct from the cohesion which would be imparted by the use of a greater quantity of more viscous binder.

I would like to ask for further information on the road trial at site No. 1 in Scotland. The paper states that the performance was unsatisfactory, but the footnote to the table says that it is giving good service after two years.

I feel it necessary to challenge strongly one of the points mentioned under the conclusions. It is implied that Northern Scotland and Ireland have similar climatic conditions to Sweden, Finland, and Norway. Ireland, at least, is relatively free from heavy frosts, and it is a little unfortunate that, in that country, knowledge of the Swedish process has already inclined road engineers to believe that a cheap and effective new method of road surfacing is at their disposal. In the light of what I have already said, I should like the authors to discuss whether they have in fact intended to imply that the Swedish system was of particular suitability for Ireland and Scotland and whether in fact it has any merits over the conventional methods normally employed in those countries, having regard to the climatic conditions which occur.

T. L. Les: The term "non-hardening cutbacks" is merely a name we have used to indicate that the rate of hardening of the NH cutbacks is appreciably less than that of the conventional slow-curing or medium-curing cutbacks. Clearly, they must tend to harden to a certain extent. Nevertheless, they remain soft for several years, and road surfaces prepared from them remain workable, while mixes prepared with slow-curing or medium-curing cutbacks harden relatively rapidly and cannot be handled long after mixing.

At the experiment in Scotland at site No. 1 it is stated in the footnote to Table IX that deterioration started after only seven months. Even though the road is still giving satisfactory performance, in view of the very light traffic we would not have regarded the surface as of satisfactory quality.

In answer to Mr Jarman's final remark, we did not intend to compare the climatic conditions in Ireland or Scotland with those found in Sweden. What we intended to indicate was that similar problems occur, due to the state of foundations under the roads in Sweden during frost break-up, and with many roads in Ireland and Scotland lying over peat-bog.

G. P. Richard: Mr Jarman suggested that his remarks are intended largely to stimulate further discussion, so I will not try to answer them in detail. I should, however, explain what we mean by immediate stripping in our immersion test. This test was devised to evaluate the potency of the amine-type adhesion agents when used with different aggregates. We did not wish to evaluate stripping over a considerable period of time, but to find out the concentration of amine in a binder which is necessary to give the binder the property of displacing water from stone. To do this, the experimental binder was mixed thoroughly with wet aggregate, and the whole was at once immersed in water. The appearance, after one minute, of uncoated fine material, making the water cloudy, was taken as immediate stripping. The quantity of amine in an aggregate/binder mix necessary to prevent immediate stripping was taken as a rough guide to the amine requirement of a given aggregate.

Dr A. R. Lee (Road Research Laboratory): This is a very interesting and informative paper and a valuable description of a piece of research which has combined experimental work both in the laboratory and on the road.

It is particularly interesting to see that the authors conclude that the surface texture and shape of the stone is more important than small variations in aggregate grading. It is also particularly interesting to note that they have found the immersion wheel-tracking test valuable in predicting the adhesive and mechanical properties of an aggregate/binder mix. In view of these conclusions, I should like to ask whether the authors have been able to formulate their results as recommendations for certain aggregates and for certain grading limits of these aggregates, similar, perhaps, to the method we adopted in our Road Note No. 16 for the wet aggregate (hydrated lime) process. There are always difficulties in arriving at reproducible results from arbitrary mechanical tests, and it is easier from the point of view of a specification to define the aggregate and the grading without referring to the results of such a test. Have the authors covered a sufficiently wide range of aggregate gradings to be able to make definite recommendations on this matter?

The second question that arises is what is the limiting

traffic intensity that will permit success with oiled gravel roads? The process was developed in the first place for lightly trafficked roads. At what traffic intensity is it necessary to change from road oil to cutback bitumen, and is there a relation between viscosity and traffic intensity?

Finally, perhaps the authors would care to enlarge on their general approach to road oiling. What, for instance, are the relative merits of a highly stable aggregate combined with an oil of low viscosity as compared with a less-stable aggregate combined with a binder which attains a high viscosity after coating?

D. H. Mathews (Road Research Laboratory): I think that the results given in Figs 2–4 should be regarded with caution; results from simple immersion tests can rarely be used as more than a rough guide, and may on occasions be misleading. However, accepting for the moment that the tests do give at least a qualitative guide to the behaviour of oiled gravel, the results in Fig 4 have rather more significance than the authors appear to believe. To me, these results suggest that we should revise our ideas on how to compute the amine content of an oiled gravel mixture. It appears better to base the amine content on the surface area of the aggregate, translating this amine content into a percentage of the oil content when we know how much oil is required in the mixture. I do not think that the amine content and oil content necessary for mixtures of varying gradings necessarily follow the same pattern.

The authors have rightly pointed out that a mixture made with wet stone may appear rich although in fact it is really lean. Our experience at the Road Research Laboratory suggests that this is most likely to be observed when the amine content is low rather than merely because the water content of the aggregate is high. When the amine content is low the oil does not coat the stone, but instead it spreads over a film of water on the aggregate. The mixture appears rich because water is trapped and the fluids content is therefore high. I think that this may also apply to the authors' mix-in-place work. Would it not be more correct to ascribe the results to an inadequate content of amine? It may well be that it is much easier and cheaper to use surface-dry aggregate than to use sufficient amine to expel the water from the mix.

The authors have described some results from their work on stability of oiled-gravel mixtures. We have also been investigating this subject using the Hveem Stabilometer. The results in Fig 6 show much the same pattern for gravels Nos 3 and 5 as we have found with similar gradings. I think that the results for gravel No. 4 show no more than that this is an unstable material which is not suitable for the oiling process. I believe that the authors may find, as we have done in a similar case, that the transient minimum at 3·0 per cent (oil content) is accompanied by a decrease in the compacted density of the mixed material made with gravel No. 5.

I note that the maximum stability for gravel No. 3 with a grading similar to the normal Swedish grading occurs at an oil content between 3·0 and 3·5 per cent. Our maximum in the Hveem test for such a grading occurs just above 3·0 per cent. I understand that the oil content now specified in Sweden is 3·2 per cent, which appears to bear out these results. It is noteworthy that our results show this type of grading to be rather critical in respect of oil content; the stability at 3·5 per cent is approximately 80 per cent of the maximum stability, and at 4·0 per cent it is only 18 per cent of the maximum. The authors' results from the modified CBR test do not show up this fall-off in stability in such a marked fashion.

We have found that some fine-textured materials (with coarse aggregate contents as low as 30 per cent) are more tolerant in that their stabilities do not fall away so sharply with increasing oil content. In one example, we obtained stabilities equal to or better than those obtained with the Swedish grading, over a range of oil contents from 2·5 to 4·5 per cent. The preliminary indications from our full-scale road experiment begun in 1959 seem to bear out these results, although it is far too early at present to be categorical on this point; it is important that sweeping conclusions are not drawn before we have adequate evidence from the road on the validity of the laboratory tests.

My final point is that stability is not the only criterion for judging a mixture. A mixture has to be both stable and durable, and lack of durability does not arise only from stripping in wet weather. We have found that it is possible for the so-called NH cutbacks to harden in service to such an extent that it is no longer possible to re-work the material. In an extreme case the material failed after the first winter on the road. This adds point to my earlier remark concerning the variation of stability with oil content. If one has a rather critical grading it is possible that the normal variations of oil content during manufacture may lead to some parts of the material being either less stable than is desired or less durable and therefore difficult to re-work.

T. L. Lee: In answer to Dr Lee's question, we really have not worked with a sufficiently large number of aggregates to be able to formulate grading specifications, nor have we sufficient data to formulate the types of gravel which, in terms of texture, are suitable. Our studies have been directed towards general applicability in any part of the world and, in this connexion, we feel that even if it were possible to formulate a grading, very often it might be difficult to meet this in the field.

We have no data regarding traffic density limitations, but field experience with the very light binder used in Sweden indicates that the sort of figures for which this type of treatment is intended may range up to 500–1000 vehicles/day.

We would like to bring out the point made in our paper which showed that when only relatively unstable aggregates are available, then mix stability has to be achieved by using more viscous types of binder.

G. P. Richard: Regarding Mr Mathews' first point, we agree that the immersion test is only a rough guide to the stripping tendencies of various aggregate/binder mixes. It does, however, indicate whether or not a particular adhesion agent can exhibit good active adhesion, when used in reasonable concentrations with a particular aggregate. We would not regard good results from this test as necessarily indicative of satisfactory performance with regard to long-term anti-stripping performance.

We would agree that aggregate surface area is probably the most important of the variables affecting the amine requirement of a mix, but we do not believe that it is a practical proposition to calculate amine requirement from surface area. In practice, the surface area will vary enormously from batch to batch of an aggregate from a single source. By using a simple immersion test on samples of varying fines content, one can fix an amine content for the mix such that, at the highest likely level of fines, active adhesion will be maintained.

In our mix-in-place work we have certainly seen the phenomena which Mr Mathews has described. However, we would emphasize that even when sufficient adhesion agent is present to secure active adhesion, visual assessment of mix quality is very difficult when the stone is wet.

In these circumstances we find that the binder adheres preferentially to the smaller particles, leaving larger stone virtually uncoated. Later, after the mix is laid, it is perfectly true that complete coating will occur, but during the mixing period this preferential coating of the smaller particles renders visual judgment of mix quality very difficult. We were pleased to hear that the work of the Road Research Laboratory using the Hveem Stabilometer is in good agreement with our own results. In conjunction with the mechanical test work, we carried out density determinations but were unable to find a transient minimum at about the 3 per cent binder content level. With regard to the differences in "percentage strength," we do not believe that it would be wise to compare the actual figures obtained in the two laboratories without the certainty that the comparison is between identical aggregates. We would make the point that the modified CBR test is essentially a quick means of deciding whether a given aggregate is suitable for this type of application. Although the test shows levels of binder above which stability is rapidly lost, we do not believe that it can be used alone to indicate optimum binder content.

Fine-textured materials certainly appear to be more tolerant of binder content than coarse, from the point of view of stability alone. However, as Mr Mathews says, this is not the only criterion of durability, which is associated with stability, resistance to stripping, and the chemical and physical stability of the binder. We wonder whether the material he quotes, containing 2·5 per cent binder, has in fact made a durable mix. In one of our own experiments we made up a mix at this binder level, which appeared mechanically stable, but became very dry and soon disintegrated in service.

Finally, Mr Matthews mentions a so-called non-hardening cutback which hardened in service. We have never experienced this type of behaviour. Sometimes we have made a somewhat lean mix which formed an indurable, unworkable surface, but this was due to absorption of binder by excess fines, and not to hardening of the binder.

P. J. Way: I would like to take the opportunity to add to the replies given by my co-authors to the comments from Dr Lee and Mr Mathews.

Dr Lee questions, in fact, the significance of results of mechanical tests. I am not prepared to join issue on the philosophy of modern mix design methods. I believe that in the U.K. road engineers tend to rely on the experience of many years, as a result of which mix specifications have been drawn up based upon aggregate gradings and bitumen specifications. On the other hand, in the U.S.A., and in some parts of Europe, there is a current tendency to use laboratory equipment to establish the stability limits of various mixes. In our work, to produce specifications in terms of grading curves would have called for a statistical approach to the subject with an enormous programme of field work, which, of course, we were unable to contemplate. We are, however, satisfied that we have good correlation between our laboratory data and field performance. Obviously, these tests have to be treated with reserve. Bearing in mind Mr Mathews' comments about being cautious in interpreting them, I would like to draw his attention to the last paragraph in our report, in which we quote: "These tests have been shown, within certain limitations, to line up fairly well with field experience, and it is believed that they can be of considerable use for the purpose. Nevertheless, some experience is required to interpret the results of these tests, and blind acceptance of them without some knowledge of the conditions existing at the site where mixing and laying work is to be carried out may lead to difficulties."

With regard to the question as to the circumstances in which we think the technique used in Sweden can be employed elsewhere, this is essentially a question of economics. Obviously, a properly designed road with prepared foundations, and so on, will in the long run prove the most satisfactory. However, there are circumstances where funds are just not available, particularly in sparsely populated areas, and authorities are faced with a choice of either carrying out a reasonably good temporary expedient which will last for some years at relatively little cost, or doing nothing at all. These circumstances usually arise where roads carry only a few vehicles a day. It is for this type of job that we have been directing our efforts.

D. C. Broome (Limmer & Trinidad Lake Asphalt Co. Ltd): I was particularly interested to read this paper and to listen to Mr Les' presentation, because I had the privilege of inspecting a considerable mileage of the oiled gravel roads in Sweden a couple of years ago, in company with Dr Hallberg, who is I suppose the pioneer of this particular scheme on this side of the Atlantic. I must say that I was most impressed with what he had to show me.

The authors have, amongst other things, brought out particularly the importance of the basic nature of the aggregate itself. With that principle, I am wholeheartedly in agreement. I rather regretted that there was one type of aggregate which was not mentioned in the authors' work, *i.e.* limestone, because I rather imagined that a limestone aggregate, or at least some types of limestone, might give most interesting results in this connexion.

I thought the idea of using a CBR, or modified CBR, was very useful, although, there again, I think one needs to be careful with all these things. I was intrigued as to why they did CBR's with a Marshall mould, but I gather from Mr Les' remarks that there is no real technical reason for it and that it was just a matter of convenience.

In Table VI, showing some of the CBR results, the very first line refers to satisfactory results with a mixture having a void content of 18 per cent. I was a little surprised at that, because I would not have thought that any mix with such a high void content would have been satisfactory. I would like to ask the authors whether it was in fact a very satisfactory one.

In Table VIII, referring to the results of the wheel-tracking tests, this seems to me to suggest that the SC oils are generally better than the NH oils, but I am not quite sure of the extent to which this is borne out in practice. I would be glad if the authors could say another word about that.

Another question arising from Table VIII is that if the SC oils are better than the NH, why could not one use the SC ones more extensively? If that conclusion is incorrect, then it does seem to me that one needs to be very careful indeed how far one uses the results of the wheel-tracking tests in this particular job.

The Uganda road trials were very interesting, but I found the reports a little confusing, and I obtained the general impression that none of the Uganda work was particularly satisfactory.

Mr Les did mention, in his introduction, one section which had been satisfactory for a time, and I wonder if he could tell us whether that has continued to be satisfactory, or whether even that section, which was made from a rather special mix, failed after a moderate time.

Finally, I would like to add yet another word of caution

to all this. I think that we should all be most grateful to the authors for presenting us with this very considerable volume of most interesting work, but I would like to join with previous speakers in hoping that one will not become over-enthusiastic about this scheme, and that its use should be very carefully restricted to situations such as that which exists in Sweden. Where those conditions do not exist, then I for one would very much favour the use of more orthodox forms of surfacing.

T. L. Les: In answer to Mr Broome's comments, the reason why we did not include limestone in our programme was a simple one. Swedish experience showed that the natural adhesion between limestone and stearine amine was not adequate when using relatively fluid binders, and led to a number of failures in the field. On the other hand, the use of amine with limestone was unsatisfactory due to the poor response of limestone to such types of agent.

With reference to Mr Broome's question about the stability of a mix used at Skye with a voids content of 18 per cent, I must say that when first laid on the road it gave every indication of lack of stability. Nevertheless, it did give satisfactory performance and it could well be that during its early life the road received very little traffic at all, and by the time the tourist traffic had begun to use the road the latter had had a chance to settle down.

Coming to the results of the wheel-tracking test, our field data confirms the laboratory prediction that SC oils are generally better than the NH oils. However, there are other factors to be borne in mind, the greatest of which is the behaviour of the binder upon weak foundations. The effect of instability of foundations is something which we could not reproduce in the laboratory. Nevertheless, experience in Sweden showed that the use of conventional cutbacks was impracticable, since they hardened to such an extent that damaged surfaces following frost could not be readily repaired.

Similarly, in Uganda it was noted that whereas sections based upon heavy non-hardening cutbacks gave reasonably good performance, test sections based upon conventional SC and MC cutbacks cracked, due to the brittleness or hardness of the binder upon foundations which deflected under traffic.

We would agree with Mr Broome that the use of more orthodox forms of surfacing should be encouraged wherever possible rather than the use of special low cost techniques such as we have been examining. However, in the long run such considerations are usually overridden by economic factors. If funds are available to construct proper foundations with an orthodox surfacing, then undoubtedly in the long run better results will be achieved. The necessary funds, however, are frequently not available, and that is why the authors considered that the technique used in Sweden was worthy of consideration in the rest of Scandinavia, and in such underpopulated areas as East Africa, etc.

D. C. Broome: In the light of Mr Les' remarks, may I put a supplementary? After what he has just said, does Mr Les think that under tropical conditions one might get even better results with an even heavier oil?

T. L. Les: Yes, provided the foundations are strong enough to prevent deflection of the surfacing, with consequent cracking.

In East Africa the usual form of construction consists of soil stabilization with lime to a depth of 6 inches, followed by double-surface dressing with an RC cutback. However, this type of construction is relatively expensive, and for that reason is normally used only for the more important roads.

F. H. P. Williams (Road Research Laboratory): I would like to confine my remarks to the use of this process in Uganda. In East Africa, as Mr Les has said, there are many miles of road of gravel surface, and these gravels, consisting of gravel–sand–clay mixes, give a very satisfactory performance provided that they are just at the right moisture. Unfortunately, in the long dry periods they dry out and become corrugated and dusty. The better ones in the wet season will stand up to traffic, although they might get a bit slippery. Just before Mr Les did his experiment in Uganda we carried out a small experiment, trying to use a rather cheaper kind of oil. The experiment was based on the premise that if we could incorporate a fluid which would not evaporate we might retain the cohesion of the clay, and thereby stop the roads corrugating, which was the main difficulty. Provided the cohesion remained and the surface can dry out, the surface is stable enough to carry the traffic. A number of binders were used: a fuel oil on its own and with percentages of 80/100 pen bitumen, and also the Swedish road oil. Unfortunately, the fuel oil reduced the cohesion of the clay, and the clay got into the fuel oil, reduced what cohesive ability that it might have had, and the road dusted and ravelled even worse than before. The oils were somewhat lighter than those Mr Les used, and in addition lower percentages of the oil were used, mainly on economic grounds, because the cost was putting it well above conventional methods of construction.

Coming to Mr Les' experiment, I think really the criterion is, when does a road fail? Engineers abroad say that provided one can drive a car along the road it has not failed. I do not suggest that the best section in the experiment has gone to anything like that extent, but after a very short period of time it was showing signs of breaking up. There were slight movements in the surface, bigger stones were pulling out, and there were other definite signs that it was not going to last a very long time.

I think that, when comparing this method with the conventional form of construction, we have to consider what residual variable we have in the surface that is left when we come to the new treatment, or subsequent treatment. The conventional form of construction used in these countries now is a lime-stabilized base of roughly 6 inches thick, with possibly a sub-base underneath it if necessary and a multiple surface dressing on top. That is giving very good service, and when the traffic rises to well over 1000 vehicles a day, as it will fairly quickly on these bitumen-surfaced roads, a 2-inch wearing course of a pre-mixed material can be added to it.

In the case of the road oil, I doubt whether after two or three years one is going to have a material that is of very much value as a base for any further improvement of the road. It will mean that even after that short period of time one has to add another mix, of road oil 2 inches thick, which again will probably last only another two to three years, because it has not sufficient stability in itself for a base.

As Mr Broome has remarked, when we come to the second stage of treatment, *i.e.* a lime-stabilized base with a surface dressing, and we want to consider putting on a cheap wearing course to carry the increased traffic, we might well consider using these naturally-occurring gravels with a more viscous "oil," to obtain a cheaper form of surfacing. I think that is a proposition well worth considering further. But I do not think that with the present price of oil in these countries, and the cost of

processing, that oiled gravel roads are going to be an economic proposition.

P. J. Way: I examined this test road in Uganda myself, about four weeks ago, and can testify that the experimental section to which Mr Les referred as having given good performance was quite intact and free of cracking or crazing. The profile of the section was poor, but this merely showed that the surface carpet had moulded itself to depressions in the foundations. In other sections, prepared from conventional cutbacks, loss of profile had been accompanied by surface cracking. I suspect, incidentally, that this experimental section would provide an excellent base for further conventional treatment without any additional attention to the old surface.

A. W. Deller (Shell Refining Co. Ltd): I wonder whether I may reinforce the warnings of Mr Jarman about the dangers of copying some of these superficially attractive systems in unsuitable circumstances, by reference to observations made in the Philippines. There is naturally, in an ex-American colony, a strong leaning towards American methods, and it looks as though the Wisconsin experiments had some influence there. However, instead of proper cutback binders, the habit is to use used sump oil, and the results of this are temporarily good. The surface produced after the unpleasant period of compacting by traffic looks quite attractive. But as soon as the rains come, and they are pretty heavy throughout nine months of the year, the surface becomes extremely slippery and large potholes appear and propagate themselves very rapidly "down stream." The result, in a very short period of time on any road—the system is used on village roads and also on secondary roads in Manila itself—is to produce, often in as little as three or four months, a very poor surface, which in wet weather can be extremely dangerous.

I. A. T. Shannon (Shell International Petroleum Co. Ltd): I have seen the work in Sweden, and work of a somewhat similar nature in the U.S.A., and was associated with road oil experiments carried out by the Indian Government in the early 1930's.

I think all who have seen the Swedish work must admire the excellent progress that the Swedes have made in adapting early American practice to fit the rather unique conditions in Sweden. The Swedish network of roads has grown up on a very parochial basis and, as the authors have pointed out, there is very heavy frost strike in almost the whole of the country. The road foundations are often very inadequate for to-day's growing and heavy traffic, especially in respect of frost-proof construction, and they suffer severely from the effect of frost heave and frost boils at the time of the spring thaw. The cost of reconstructing the Swedish network with frost-free foundations would be very great indeed, and I think it is this frost problem that is largely responsible for the development of this road oiling process in Sweden. It is an essential part of the process that it must be re-workable, and that it fits in with a road maintenance system, based on highly mechanized methods.

In countries where there is not the same degree of frost problem and possibly the same degree of mechanization of maintenance, I doubt whether the process is quite so attractive. I would fully agree with the authors that the road oiling method as developed in Sweden has good prospects in Finland, where I believe it is now being used on a large scale, and presumably also in Norway. But when we come to the hotter countries I feel somewhat doubtful that it has the prospects which the authors see. The Indian Government first took an interest in road oiling in the early 1930's and, although not closely associated, I was aware of experimental work being carried out on the Rotak road in Delhi, on four roads near Loralai, and one in the Zoab Valley in Baluchistan. In those days we did not have all the guides to design that are present to-day; stabilities by Marshall, Hveem, and other methods were not available, understood, or developed. The gravels used had reasonable grading curves, however, and binders were of a type which I think would now be called either an MC4 or MC3, or an SC3 and SC4.

The Rotak road in Delhi was a very quick failure on account of lack of stability. The traffic there was admittedly heavy, with tyre pressures (steel tyres) probably greater, not only than anything in Sweden, but anything one would get in the U.K. to-day. In Baluchistan, on the other hand, where the traffic was comparatively light, results were better, but failure in time was largely, as far as I can recall, due to lack of stability. In this region, where traffic conditions were perhaps more similar to those in under-developed areas to-day, it was eventually found, I believe, that conventional low cost methods of construction, involving water-bound macadam or mechanically stable gravel, sealed with conventional forms of surface dressings, did give a very adequate answer which at the time could not be obtained with any certainty in these early road oiling experiments.

The meeting then closed with a hearty vote of thanks to the authors.

CONTRIBUTED DISCUSSION

J. G. Hurst (Petroleum Specialties Ltd): It would be interesting to know to what extent the various treatments increase the mechanical stability of the aggregates. Can the authors extend the information given in Table VI and Fig 5 to include the untreated aggregates?

Can they also say whether the treatments in Sweden and Uganda have been effective in avoiding the formation of corrugations?

G. P. Richard: We have done only a very limited amount of work on untreated aggregates, but as an example we can state that with a Swedish morainic gravel with no binder or water the modified CBR test gave a value of 1300 psi at 0·1 inch penetration. When 3·5 per cent of Swedish non-hardening cutback was present the value was raised to 3300 psi.

In reply to the question regarding the formation of corrugations, no such phenomena have been observed on the oiled gravelled roads of Sweden. However, I must confess that I have not seen these corrugations even on the untreated roads in that country. Corrugation is a very serious problem with the quartzitic and laterite roads in East Africa, but I understand from Mr Way that during his recent examination of the road in Uganda there were no signs of corrugation on any of the treated sections.

JET FUEL THERMAL STABILITY STUDIES BY ELECTRON MICROSCOPY *

By ROBERT K. JOHNSTON † and J. E. SHAMBLIN ‡

INTRODUCTION

THERMAL instability of present-day jet fuels is primarily a problem in gum and sediment formation, accelerated by high temperatures and by oxygen dissolved in the fuel. In view of the complexity of the chemical reactions involved, the problem has been studied largely on an empirical basis. The currently accepted method of test is the CFR fuel coker test (ASTM D1660–59T), in which some 5 gallons of fuel are pumped through a heater and test filter over a period of 5 hours; fuel degradation is measured by the extent of hot-surface deposits and filter plugging.

The investigation of fuels for supersonic aircraft has led to several approaches in studying the thermal stability problem at extreme temperatures. One is the development of the CRC high-temperature research fuel coker, which is basically an extension of the CFR fuel coker into the extreme-temperature region. The complexity, cost, and sample requirements of this apparatus have made it necessary to develop rapid small-scale methods for screening and selection of hydrocarbons as fuel candidates. One such approach is the use of an isoteniscope for measuring threshold temperatures of decomposition based on vapour pressure measurements. This approach provides basic data on hydrocarbon decomposition temperatures, but ignores the possibility of deposit formation at temperatures far below that for decomposition of the bulk hydrocarbon. Such deposit formation does in fact occur, even in commercially pure hydrocarbons, and is probably caused by trace impurities.

In a programme recently completed at Southwest Research Institute under United States Air Force sponsorship,§ a technique and rating method have been developed for study of fuel thermal stability, based on examination of deteriorated fuels by electron microscopy. This technique was selected after consideration of other methods of particle size estimation such as optical microscopy and light scattering. The use of electron microscopy has advantages in clear definition of particle size in the sub-micronic region and direct indication of particle size and shape.

Electron microscope techniques have been used widely in the study of lubricating oils and greases, but have found fewer applications to distillate fuels. One example of the use of such techniques in jet fuel thermal stability studies was given by Johnson, Fink, and Nixon [2] in 1954. More recently, published work by Chertkov and Shchagin [1] has included a fairly extensive use of electron microscopy in thermal stability studies on Soviet jet fuels.

The work reported herein is concerned with the development of rating techniques for degraded fuels, based on electron microscopy, and the application of these techniques to a variety of hydrocarbon fuels.

TEST FUELS

The fuels for this programme, supplied by the Propulsion Laboratory of Wright Air Development Division, included a group of high-temperature fuel candidates as well as several conventional JP–4 fuels, as follows:

HTF–12	Partially hydrogenated terphenyls
HTF–15	Petroleum product
HTF–16	Light petroleum oil
HTF–27	*iso*Propylbi*cyclo*hexyl
HTF–32	Decalin
HTF–34	Dimethanodecalin
HTF–35	Alkyl decalin
HTF–59–10	Petroleum product
HTF–59–11	9-(2-ethylhexyl)perhydrofluorene
HTF–59–14	Pinane
HTF–59–18	Hydrogenated coal tar cut
F–56–6	JP–4 fuel
F–57–20	JP–4 fuel
F–58–4	JP–4 fuel
F–58–12	JP–4 fuel

Selected inspection and analytical data on the HTF fuels are given in Table I. These materials are hydrocarbons or petroleum products with predominantly cyclic structures, and are representative of classes of materials being considered as high-temperature fuels. No information was obtained in this programme on the purity of the hydrocarbons, except as indicated by the distillation data in Table I. None of the hydro-

* MS received 30 December 1960. Presented before the Division of Petroleum Chemistry, American Chemical Society, 16 September 1960.

† Southwest Research Institute, San Antonio, Texas.

‡ The University of Texas, Austin, Texas.

§ This work was performed under Contract AF 33(616)–5702, monitored by the Propulsion Laboratory, Wright Air Development Division, United States Air Force.

TABLE I

Fuel Inspections and Analytical Data

HTF fuel code:	12	15	16	27	32	34	35	59–10	59–11	59–14	59–18
Gravity, API/60° F	11·3	32·9	28·7	28·0	27·5	9·0	32·5	53·3	24·0	33·1	35·3
Distillation:											
Ibp, ° F	230	421	506	535	371	438	418	349	620	328	384
10%, ° F	640	446	555	538	373	450	425	371	650	328	400
50%, ° F	668	494	615	540	375	455	428	381	662	333	419
90%, ° F	716	620	700	547	378	458	430	435	666	335	443
Fbp, ° F	745	728	720	573	406	496	469	555	689	364	488
Aromatics, FIA, %	100	2	1	5	2	5	2	0	1	—	—
Olefins, FIA, %	0	0	0	0	0	0	0	1	0	—	—
Sulphur, %	0·001	0·004	0·040	0·006	0·006	0·000	0·003	—	—	—	—
Mercaptan sulphur, %	0·0004	0·0003	0·0003	0·0002	0·0003	0·0001	0·0000	—	—	—	—
Carbon, %	90·65	86·69	87·10	88·94	87·21	88·74	87·15	—	—	—	—
Hydrogen, %	9·30	13·61	12·69	13·25	12·76	11·03	12·81	—	—	—	—
Aniline point, ° F	72·7 *	165	167	144	93	92	128	—	—	—	—
Net heat, MBtu/lb	17·34	18·39	18·35	18·40	18·30	17·95	18·22	18·72	—	—	18·44
Freezing point, ° F	+61	−50	<−76	+4	<−76	+70	−46	−63	—	—	—
Pour point, ° F	−30	<−75	<−75	<−75	<−75	+70	<−75	—	—	—	—
Viscosity, cS at											
100° F	18·0	3·5	—	6·3	—	7·8	1·89	1·68	26·4	1·85	1·74
0° F	4045	23·6	195	101·6	8·06	—	6·74	6·29	—	—	—
−40° F	—	105	2505	—	18·01	—	—	16·2	—	14·8	15·6

* Mixed aniline point.

carbons in this group is " pure " in the sense of consisting mainly of a single compound; in most cases these " near-pure " hydrocarbons are believed to consist predominantly of related isomeric compounds.

EXPERIMENTAL

Fuel samples were heated in sealed stainless steel tubes, designed as shown in Fig 1. The ¼-inch tubing and the fitting are Type 316 stainless steel. Total internal volume is 9 ml. With a 3-ml fuel sample, 25 per cent decomposition to carbon and hydrogen can occur without exceeding the rated pressure of 7200 psi at 1300° F. Although actual operating conditions are far less severe in terms of temperature and extent of decomposition, the tubes are handled by remote control when heating.

A new tube is used for each test, and the tube and fitting are cleaned thoroughly by brushing and flushing with solvents, finishing with hexane which has been pre-filtered through an 0·45-micron Millipore filter.

After charging with a similarly pre-filtered 3-ml fuel sample and sealing, the assembly is lowered into a stirred heating bath for 5 minutes. An oil bath has been used for tests at moderate temperatures, and a lead–tin bath for tests at higher temperatures. By tests on an instrumented tube it was determined that the sample temperature comes to within 5° F of the bath temperature within about 45 seconds after immersion. After removal from the bath, the tube cools rapidly in air, and is further cooled by rinsing the outside with solvent. When cool, the tube is opened and its contents transferred to a clean particle-free bottle for subsequent use in preparing the specimens for electron microscope examination. The time from the end of the heating period until transfer of the fuel to the bottle does not exceed 10 minutes.

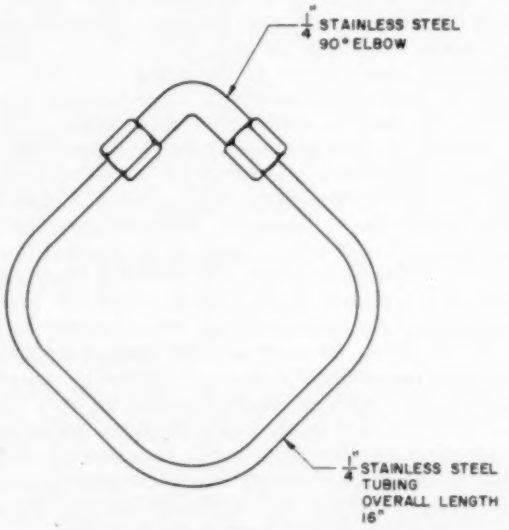


FIG 1

SEALED TUBE FOR HEATING FUELS

Within 1 to 6 hours after the heating operation, each fuel sample is agitated and then used to prepare three specimens by direct application of a drop of the fuel to the specimen support grid (collodion-coated 200-

mesh copper screen), followed by draining and then holding under vacuum for at least 15 hours at 10^{-5} mm. This is a relatively easy method for preparation of large numbers of specimens, and also avoids the use of solvents which can change the characteristics of the solid deposits. A few specimens have been prepared using the more conventional technique of centrifuging out the deposits on to the grid (30 minutes at 600 RCF), then draining the grid and rinsing with pentane.

Examination of the specimens is conducted with an RCA Model EMU–3C electron microscope. More than 100 openings in each grid are observed, scanning at 2000× with frequent changes to 30,000×. At least two micrographs are made for each fuel sample for purposes of record and comparison. The choice of location in the grid for these micrographs is dictated by the types of particles observed in the scanning, *i.e.* the micrographs are designed to show typical particles rather than exceptional particles. Ratings of the sizes, types, and frequency of occurrence of particles are based on the observations while scanning, as well as on the micrographs.

About eight fuel samples (24 specimens) can be scanned and micrographed in an 8-hour day.

RESULTS AND DISCUSSION

A wide variety of sizes and types of particles was observed in the fuels after heating. The primary particles are round and usually less than 1 micron in diameter. There is a definite tendency towards aggregation of the primary particles; branched strings or chains of the primary particles have been observed up to 20 microns in major dimension, some of them quite similar to those observed in benzene smoke or in the particulate matter from automobile exhaust gases. This tendency towards aggregation was also noted by Johnson, Fink, and Nixon [2] and by Chertkov and Shchagin.[1]

Discussion of Sampling Techniques

Since there are several steps in the sample handling procedure which could introduce difficulty with non-representative samples, each will be discussed in some detail.

At the beginning of the heating period the fuel sample is presumably agitated rather thoroughly by thermal currents and incipient or actual boiling as the pressure builds up inside the sample tube. The total heating period is only 5 minutes, followed by a maximum of 10 minutes cooling; there does not appear to be any possible problem with sedimentation during this time. The possibility of the adherence of particles to the walls of the tube (varnish or lacquer formation) was investigated qualitatively during the early stages of the programme by cutting open a number of the tubes and inspecting them visually. No detectable deposits were found in any case. The maximum test temperature included in this inspection was 500° F, so that the possibility of wall deposits at higher temperatures is not excluded. However, it may be noted that the test conditions (for which tube inspection was performed) did include those giving severe formation of insolubles for the particular fuels, and did include temperatures beyond the " peak " particle formation, as will be discussed subsequently.

After sample cooling and total transfer to the sample bottle, it may remain for as long as 6 hours before preparation of the specimens. This waiting period was dictated by practical considerations of scheduling. However, it is recognized that some sedimentation of the larger particles may occur in this period. Stokes-law calculations based on spherical particles with density 1·0 indicate that particles as small as 5 microns may be subject to sedimentation with the particular container geometry and properties of the fuels used. Since larger particles were in fact observed, it may be assumed either that the actual settling velocities did not follow the simple Stokes-law calculations, or that the particles did not adhere to the container upon settling and were readily dispersed by agitation. For a more rigorous study, it would be desirable to standardize on the shortest feasible time interval between heating period and specimen preparation.

The use of three separate specimen grids serves to eliminate questions of non-uniformity of the actual material scanned by electron microscope. With rare exceptions, all three specimens from a given fuel sample showed the same types and qualitatively the same amounts of particles.

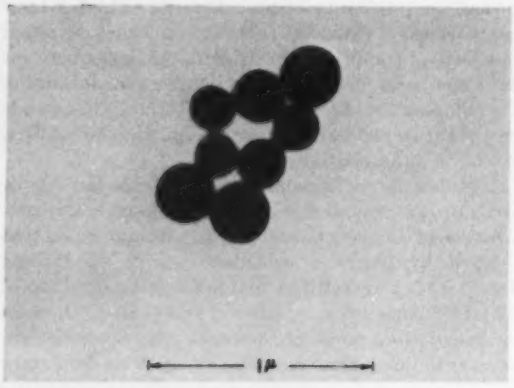
Rating Methods

In order to make valid comparisons of fuels, it was found necessary to develop a semi-quantitative method of rating particle size, shape, and quantity or frequency. Particle size can be estimated readily from the scanning and the micrographs, and is sufficiently uniform that a size or range of sizes can be assigned unambiguously.

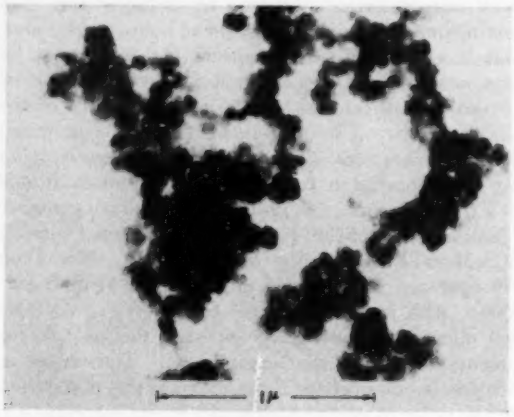
Particle shape may be broadly classified as individual round particles (" dots ") or as aggregates. The aggregates appear to fall into five general types, as shown in Fig 2. These may be described as follows, purely on the basis of their appearance and without attempting to define their true physical nature:

Type 1—Groups of round dots.
Type 2—Groups of non-circular particles.
Type 3—Groups of particles with the appearance of dried-up or collapsed spheres.
Type 4—Amorphous-appearing masses with finely divided material apparently dispersed in them.
Type 5—Large, well-defined but irregular shapes. Seldom observed; may be extraneous.

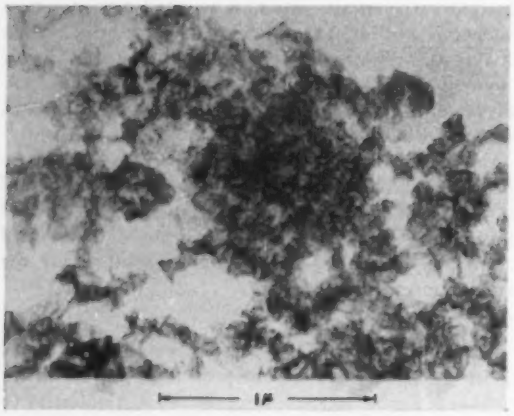
Particle quantity estimation has been based primarily on the scanning rather than on individual micrographs. Rigorous particle counting methods have not been attempted, but rough estimates of



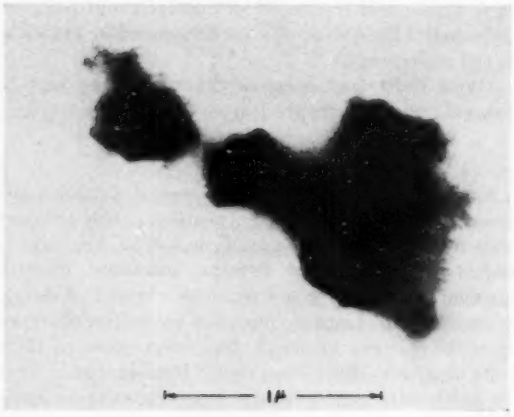
(a) Type 1



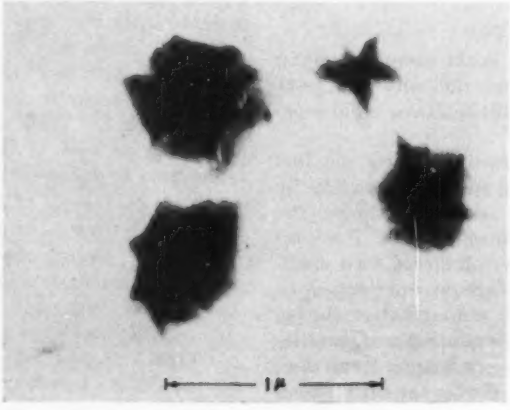
(b) Type 2



(c) Type 3

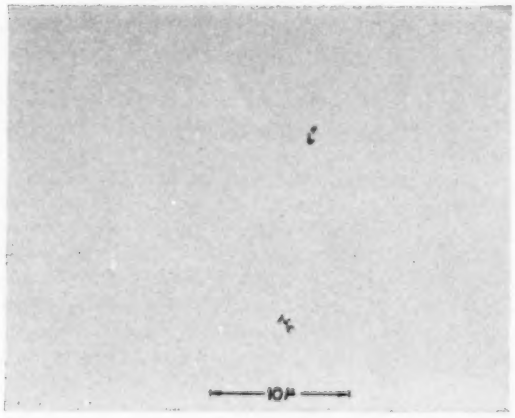


(d) Type 4

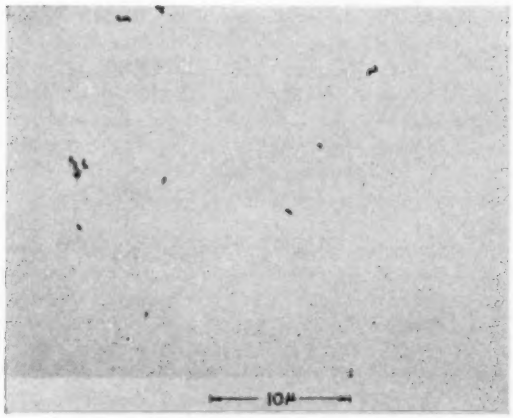


(e) Type 5

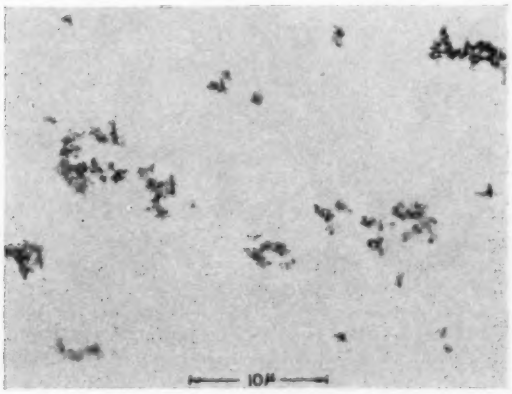
FIG 2
AGGREGATE TYPE CLASSIFICATION



(*a*) "Few"



(*b*) "Some"



(*c*) "Many"

FIG 3

AGGREGATE FREQUENCY CLASSIFICATION

particle frequency have been made on the basis of "few," "some," and "many." Typical micrographs at 2000× illustrating these classifications are shown in Fig 3.

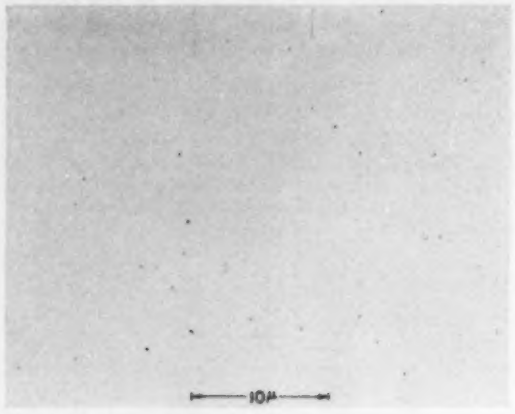
TABLE II

Electron Microscope Observations

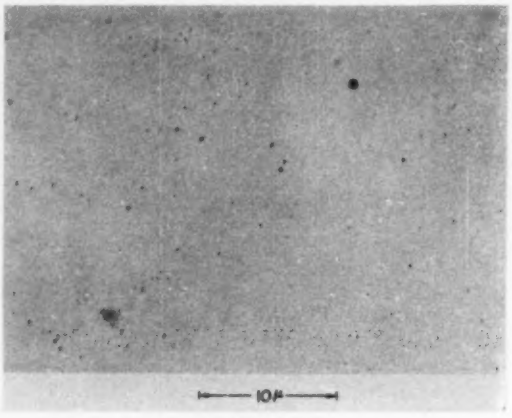
Fuels heated 5 minutes in stainless steel tube

Fuel code	Temp, °F	Individual particles		Aggregates		
		Number	Size, μ	Number	Type	Size, μ
F-56-6	250	Some	0·3	Few	4	2
	275	Some	1·0	Some	1	5–7
	300	Some	1·5	None	—	—
	325	Some	1·0	None	—	—
	350	Few	2·5	None	—	—
	400	Many	0·1	Few	4	4
F-57-20	250	None	—	None	—	—
	275	None	—	Some	2, 4	2
	300	None	—	Many	5	1–2
	400	None	—	Some	1	2
	500	Many	0·1	Some	4	5
F-58-4	250	None	—	Many	2	1
	275	None	—	Many	2	2
	300	None	—	Many	2	8
	350	None	—	Many	1	>10
	400	None	—	Many	1, 2	>10
F-58-12	275	None	—	None	—	—
	300	None	—	None	—	—
	325	None	—	Few	1, 2	2
	350	None	—	Some	4	2
	375	None	—	Some	4	3
	400	Some	1·0	Some	4	3
	450	Few	0·7	Some	4	8
	500	Few	0·7	Some	4	3
HTF-12	400	Some	<0·1	Some	2, 4	7
	500	None	—	Some	2, 4	6–12
	600	None	—	Few	4	3
	700	None	—	Few	4	3
HTF-15	200	None	—	None	—	—
	250	None	—	None	—	—
	300	Many	0·1	None	—	—
	350	Many	0·5	None	—	—
	400	Many	0·1	Few	1	2
	450	None	—	Many	2	4
	500	None	—	Many	2	10
HTF-16	325	Few	1·0	Few	*	2
	350	Few	0·5	Some	4	2
	375	Few	0·5	Some	1, 4	3
	400	Many	0·1	Many	2, 4	15
	450	None	—	Many	2, 4	15
	475	None	—	Many	2, 4	15
HTF-27	400	Many	0·1	Some	1	5
	500	Many	0·1	Some	2	6
	600	None	—	Many	2	7
	700	Many	0·1	Some	3	1
HTF-32	400	Some	1·5	Some	1	2–4
	500	None	—	Some	2, 3	7
	600	None	—	Some	2, 3	10
	700	None	—	Some	3	—
HTF-34	400	Some	1·5	Few	1	2
	500	None	—	Many	2	6–10
	600	None	—	Many	2	20
	700	None	—	Some	2, 3	7
HTF-35	400	Some	1·0	Some	1	2–4
	500	Many	0·1	Few	2	3
	600	Few	1·0	Some	2	6–8
	700	None	—	Many	3	5–6
HTF-59-10	300	Many	0·1	Some	2, 4	5–7
	400	Few	0·7	Some	2, 4	5–7
	500	None	—	Some	3	2–6
	600	None	—	Few	3	5–7
	700	Some	0·1	Few	2, 3	2–3
HTF-59-11	300	Many	0·1	Few	2, 4	1
	400	Many	1·0	Few	1, 2	3
	500	Many	0·1	Many	2	7–10
	600	None	—	Some	2	7
	700	Few	0·2	Many	3, 4	1
HTF-59-14	400	Few	1·0	Few	3	1
	500	None	—	Few	3	6
	600	None	—	Some	3	5
	700	None	—	Few	3	7
HTF-59-18	400	Many	0·1	Many	4, 2	1
	500	Many	0·1	Some	3	5
	600	Many	0·1	Few	3	5
	700	Many	0·1	Many	5	1

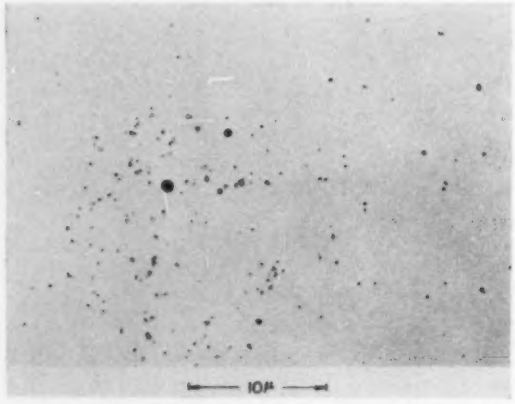
* Probably extraneous dirt.



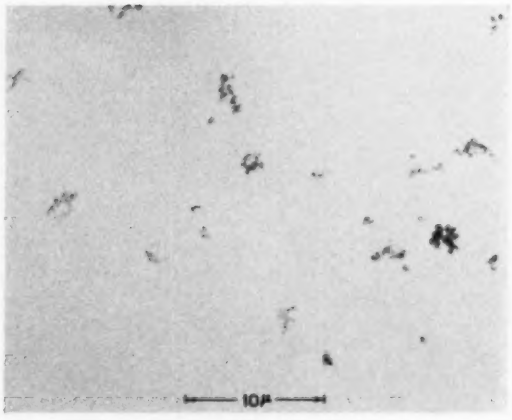
(*a*) 300° F



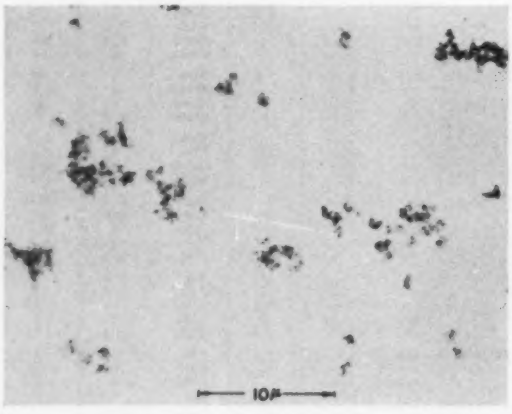
(*b*) 350° F



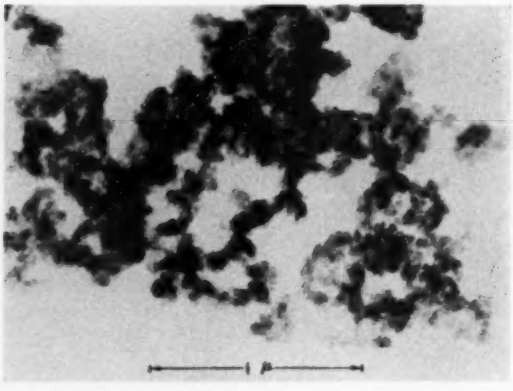
(*c*) 400° F



(*d*) 450° F



(*e*) 500° F



(*f*) 500° F–(30,000×)

FIG 4

EFFECT OF TEMPERATURE ON PARTICLE FORMATION IN HTF–15 FUEL

Effect of Test Temperature

Electron microscope ratings over a range of test temperatures on each fuel are shown in Table II. Some fairly definite trends can be noted in these data. Very often as aggregate formation becomes more pronounced at higher temperatures, the individual particles disappear, indicating that the latter represent the initial stage of deposit formation. This trend is illustrated in typical micrographs shown in Fig 4. Below 300° F HTF–15 does not form any significant deposits. From 300° to 400° F the individual particles are present in fairly large quantity; at 400° F the first Type 1 aggregates appear; above 400° F the primary particles disappear and the aggregates are larger and mostly in the Type 2 form.

For many fuels, aggregate size and quantity tend to increase with increasing temperature up to a maximum, and then drop off with further increase of temperature. This maximum in aggregate size and/or quantity was observed on two of the JP–4 fuels at 275°–300° F and on several of the HTF fuels in the region of 600° F. Similar reversals for deposit quantity and filter plugging rates have been reported by numerous investigators.[2,4–7] Several explanations have been advanced, including changes in the shape or rigidity of the particles and dispersion (peptization) or actual redissolving (depolymerization) at higher temperatures.

The trends in aggregate type *v.* temperature are somewhat indefinite, except that there is a tendency to go from Type 1 aggregates to the other types as the test temperature is increased. It will be noted that no Type 1 aggregates were found in any tests above 400° F. It appears probable that the mechanism of formation of the Type 1 aggregate is somewhat different from those of the other types.

Postulated Mechanism of Aggregate Formation

The disappearance of the primary particles and the appearance of aggregates at higher test temperatures may be explained if a certain critical size of the individual particles is assumed necessary for aggregation to occur. An inspection of the data of Table II shows that the primary particles rarely attain a size of more than 1·5 microns. Disappearance of the primary particles (as temperature is increased) coincides with or overlaps the temperatures for the appearance of aggregates in too many instances to be regarded as fortuitous.

If the derivation of aggregates from initial primary round particles is accepted, then it is possible to visualize the mode of formation of the principal types of aggregates. At a moderate temperature, at which the primary particles grow to critical size rather slowly, aggregation takes place during the later stages of the heating, after the primary particles have developed fully and attained a relatively high degree of polymerization. Under these conditions, little distortion of the primary particles would be expected to occur, and Type 1 aggregates would be formed. At higher temperatures, if the primary particle growth tends to outrun the degree of polymerization, aggregates would be formed from particles while in a semi-fluid state, favouring the formation of distorted aggregates. The higher temperature would also contribute to increased fluidity of the particles for any given degree of polymerization. An alternate explanation for the formation of distorted aggregates would be the early formation of non-distorted Type 1 aggregates at intermediate temperatures encountered during the initial heating period, followed by softening and distortion at the final temperature, either through a direct viscosity–temperature effect or by depolymerization at the higher temperature.

The foregoing are presented solely as hypotheses giving a reasonable explanation of the phenomena observed; insufficient data are available to draw firm conclusions on the applicable mechanisms.

The apparent reduction of *total* particle quantity at the highest temperatures in some of the test series may be a function of depolymerization. However, loss of very large particles in sample handling is a possibility that cannot be excluded. As mentioned previously, no tube interior deposits were evident by visual inspection in a few test series, some of them including this type of reversal in quantity of insolubles suspended in the fuel. A more detailed and rigorous examination of such reversals would be necessary to determine the fate of the particles at temperatures above that of the reversal.

Relative Ratings of Fuels

In order to compare the thermal stability of fuels, it is necessary to set up some arbitrary standards to define failing temperatures or " break-points." For the fuel coker this is usually defined arbitrarily as the lowest pre-heater temperature which gives either (*a*) a pre-heater rating of No. 3 or darker, or (*b*) a filter pressure drop of 13 inches Hg or more. For the electron microscope work, the break-point was defined as the lowest temperature giving definite aggregates of Types 2, 3, 4, or 5 or of more than 5-micron size. By this definition, tests showing only " few " aggregates are not considered as failing.

Using these definitions, break-points have been determined for the group of test fuels by both methods. The fuel coker break-points were determined at Southwest Research Institute [3,4] based on research fuel coker test data. For both the electron microscope and fuel coker data, the temperature increments were as much as 100° F, so that some of the break-points cannot be regarded as precise. However, a generalized correlation does exist between the two sets of data, as shown by Fig 5. It will be noted that none of the points is more than 100° F off the 1 : 1 correlation line.

A definite advantage was shown for the near-pure hydrocarbons in this group of fuels, as illustrated by the following break-point temperatures from the electron microscope ratings:

JP–4 fuels	250°–350° F
Petroleum and coal tar derivatives	300°–450° F
Hydrogenated terphenyls	400° F
*iso*Propylbi*cyclo*hexyl	500° F
Decalin	500° F
Dimethanodecalin	500° F
Alkyl decalin	600° F
9-(2-ethylhexyl)perhydrofluorene	500° F
Pinane	600° F

The same general alignment is given by the fuel coker ratings.

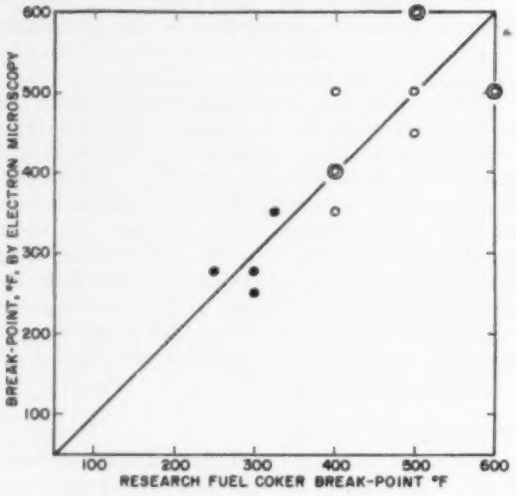


Fig 5

CORRELATION OF ELECTRON MICROSCOPE AND FUEL COKER RATINGS

● JP–4 fuels
○ HTF fuels

Various mechanical aspects of the fuel coker test make it improbable that any more direct correlation can be obtained. For example, the fuel coker results are influenced by volatility; local hot spots and incipient boiling in the preheater can cause fuel failure, even though the fuel is perfectly stable at the nominal fuel-out temperature. It is considered significant that any correlation exists at all; this indicates that the electron microscope is defining fuel behaviour that is important in terms of currently accepted empirical standards.

Effect of Heating Time and Tube Material

A single series of tests on HTF–27 with a 20-minute heating period showed a break-point temperature some 100° F lower than in the 5-minute tests.

The effect of tube material was investigated for two fuels by comparing mild steel with stainless steel tubes and fittings. As can be seen in Table III, the mild steel had a slight deleterious effect on HTF–15 as compared to stainless steel, lowering the break-point by some 50° F. Similar data obtained on HTF–27, while less conclusive, indicated the same trend. This trend was unexpected, since stainless steel had previously shown a pronounced catalytic effect on fuel

Table III

Effect of Tube Material

Aggregates formed in HTF–15 with 5-minute heating

Tube material	Temp, °F	Aggregates		
		Number	Type	Size, μ
Stainless steel (316)	350	None	—	—
	400	Few	1	2
	450	Many	2	4
	500	Many	2	10
Mild steel (1015)	350	Few	1	3–7
	400	Some	2	10
	450	Many	2, 3	7
	500	Many	2, 3	7

degradation in the CRC research fuel coker.[4] However, in that work the stainless steel was compared only with aluminium. From the electron microscope work, it appears possible that iron is the more critical metal, whereas previously the nickel content of the stainless steel had been suspected. Evidently more study is needed on a variety of metals to define relative catalytic effects in fuel degradation.

Although the limited work on heating time and tube material does not permit any general conclusions, it demonstrates that the technique is sufficiently sensitive to study the effect of operating variables affecting thermal stability.

Effect of Additives

One series of tests was run on HTF–16 containing a thermal stability additive. The data in Table IV

Table IV

Effect of Thermal Stability Additive

Fuels heated 5 minutes in stainless steel tube

Test fuel	Temp, °F	Individual particles		Aggregates	
		Number	Size, μ	Number	Size, μ
HTF–16	350	Few	0·5	Some	2
	400	Many	0·1	Many	15
	450	None	—	Many	15
HTF–16 + Additive C	350	None	—	None	—
	400	Many	0·1	Many	4
	450	Many	0·1	Many	4

indicate rather clearly the dual effect of this additive. At 350° F the formation of solids was effectively sup-

pressed, presumably by anti-oxidant action. At higher temperatures the additive reduced particle size of the insoluble material, presumably due to its dispersant action. Thus the technique described herein appears to be applicable to screening and comparison of additives. This technique gives information on the mode of action of the additives, which is not obtainable in conventional thermal stability tests.

Comparison of Specimen Preparation Techniques

The preparation of specimens by direct application and evaporation of the fuel offers considerable advantage in ease of manipulation and also avoids the ambiguity introduced by solvent treatment of the residues in conventional techniques. However, the evaporative technique does introduce the question of whether the particles observed represent insoluble material in the fuel sample or soluble gums which were precipitated upon evaporation of the fuel.

Comparative tests were run on four samples (different fuels and test temperatures), preparing specimens by the evaporative technique and by centrifuging the 3-ml sample over the grid. In each case the same types of aggregates were observed in the two grids prepared by the two methods, as illustrated in Fig 6. Thus it appears that the particles observed by the evaporative technique do represent insoluble material in the fuel samples.

There is a tendency for the centrifuged samples to show relatively more aggregates and fewer individual particles than the evaporated samples. Part of this effect may be a simple masking of the smaller particles by the large number of aggregates that are precipitated. However, it is suspected that the relative lack of smaller particles may be caused by particle size classification during centrifuging. Stokes-law settling velocities at 600 RCF are 0·06 cm/minute for 1-micron spherical particles, and 0·0024 cm/minute for 0·2-micron particles (basis—particle density 1·0, fluid density 0·88, fluid viscosity 4 cP). Thus the smaller particles cannot be centrifuged out in a reasonable time in conventional moderate-speed centrifuges.

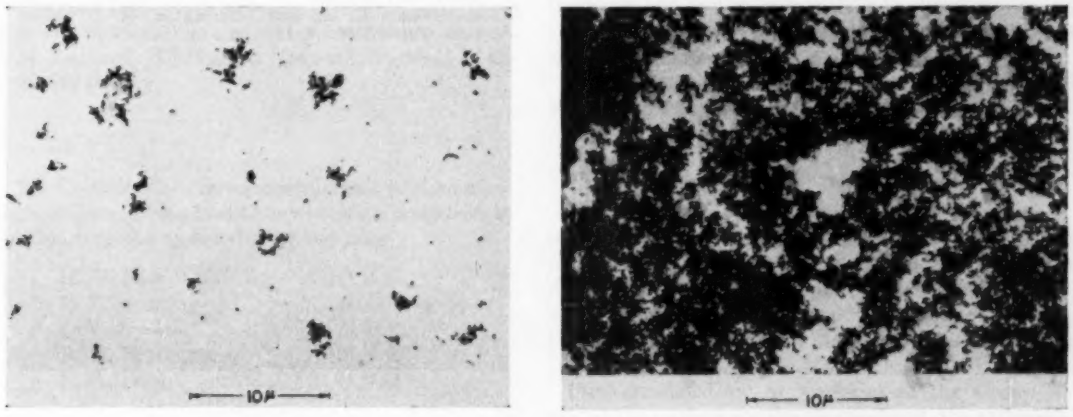
Since the evaporative technique circumvents this and other questions, it appears to be well adapted for studying distillate fuel stability.

CONCLUSIONS

A technique has been developed for rating fuel thermal stability by electron microscope examination of the particles formed in fuel samples after heating. The present technique permits the use of 3-ml samples. Thus experimental materials which are available only in research quantities may be examined for possible utility as high-temperature fuels. Semi-quantitative methods have been developed for rating particle shape, size, and frequency. Results for a given material are expressed in terms of a " break-point " temperature, which has been shown to correlate with break-points determined in a larger flow-type apparatus, the CRC research fuel coker.

Apart from its use in defining the thermal stability of experimental hydrocarbon fuels, the technique appears to have utility in investigating such questions as the mode of action and effective temperature range of fuel thermal stability additives and the relative catalytic effects of metals upon fuel deterioration.

The use of the electron microscope permits the direct examination of particle size, shape, and frequency of occurrence, without many of the questions of interpretation that arise in indirect methods of examination. The rather limited amount of experimental work herein



(*a*) Evaporated (*b*) Centrifuged

FIG 6

COMPARISON OF SPECIMEN PREPARATION TECHNIQUES (HTF–15, 450° F)

reported has furnished the basis for postulated methods of aggregate formation. It is believed that the general technique, with further refinements and in combination with other methods of analysis, will be useful in any systematic and fundamental study of the factors affecting fuel degradation. For example, reduction of sample size to 0·1 ml and a corresponding reduction of container size would be entirely feasible, and would minimize heating and cooling time as an aid to studying the kinetics of breakdown.

The formation of insoluble material in fuels is probably the most important practical aspect of thermal stability problems. Since other miniaturized techniques of evaluation have in general been based on criteria other than that of insolubles formation, the electron microscope technique affords one of the most promising means of further theoretical and practical study of fuel deterioration at high temperatures.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Dr George Pish and Gay Morrison of the Department of Materials Research, Southwest Research Institute, for their contributions in the electron microscope work.

References

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[2] Johnson, C. R., Fink, D. F., and Nixon, A. C. *Industr. Engng. Chem.*, 1954, **46**, 2166.
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THE INSTITUTE OF PETROLEUM

ANNUAL REPORT

For the Year Ending 31 December 1960

General

The year 1960 has been one of considerable progress with the membership continuing its steady rise. Mr J. M. Leonard, M.I.Chem.E., became President of the Institute in May.

Honours

The Council offers its congratulations to the following members of the Institute who were honoured by Her Majesty the Queen during the year:

H. E. Barry . . .	O.B.E.
P. L. Hunting . .	Knighthood
J. V. Jones . . .	M.B.E.
R. G. Protheroe . .	M.B.E.
F. B. Thole . . .	O.B.E.

General Meetings

Eight General Meetings were held during the year, and attendances at these meetings, though reasonably well maintained, showed some decline as compared with previous years.

Annual Dinner

The Guest of Honour at the Annual Dinner, held as usual at Grosvenor House, was the Right Honourable Richard Wood, M.P., the Minister of Power. Over 1400 members and their guests were present.

Summer Meeting

The Summer Meeting was held at Bournemouth, with about 150 members and their wives participating.

Studentship

The Institute's Annual Prize at the Imperial College of Science and Technology was awarded to Mr K. J. Henley, and Mr A. Quitwai received the Institute's Annual Scholarship award at Birmingham University.

Branches

The Institute's twelve Branches have been very active during the year, with both membership and meeting attendances well maintained.

A very successful and well attended Children's Oil Exhibition was held by the Essex Branch.

The Economics and Operations Group

The Group held seven meetings during the year and, as required by Council, submitted one paper for presentation at a General Meeting of the Institute. For the 1959/60 session it put forward a most stimulating paper on "Energetic Forecasting" by Mr Philip Chantler, Economic Adviser to the Ministry of Power.

Subjects discussed at meetings of the Group included the outlook for the air transport, the rail transport, and the electricity industries, the prospects of Saharan oil, and the European international organizations affecting the oil industry. A joint meeting was held with the Exploration and Production Group on problems in the development of a new area.

The average attendance at the Group's meetings was 51.

Education Committee

Work continued on the proposed revision of the syllabus for the City and Guilds of London examinations on petroleum. A working party was set up, composed mainly of training officers from the oil companies, who prepared a detailed syllabus for a two years course of studies. This was approved by the Committee and submitted to the City and Guilds Institute at the end of the year. One of the objects of the Committee's recommendations is to make it possible for students to prepare for the examination even if, being in some distant part of the country or abroad, they cannot attend lectures at some college or school.

The Committee was requested by Council to consider the adequacy of the present facilities for under-

graduate and postgraduate training in the U.K., with particular reference to overseas students who want to specialize in petroleum. An interim report to Council was being considered at the end of the year.

Engineering Committee

The Sub-Committees have been actively engaged in revising the various Safety Codes. The Drilling and Production Safety Code, which has been completely rewritten, should be available for publication during 1961. The format of the Electrical Code has been changed, and several of the chapters have now been re-drafted by the Electrical Sub-Committee. Good progress is also being made with the Airfield Code and the revisions of the Tanker and Marketing Safety Codes, and the Safety Sub-Committee has maintained its interest in safety problems.

A special *ad hoc* group has been set up to study ship–shore bonding, a problem which is receiving attention in a number of directions.

From the growing number of inquiries of a technical nature which have been received from Local Authorities and others in this country and abroad, it is evident that considerable importance is attached to the IP Safety Codes and to the advice of the Committee.

Exploration and Production Group

The Exploration and Production Group began its active life in 1960, and the following lectures have been given:

R. H. W. Hamilton "Oilfields—Past, Present, and Future."
F. E. Wellings. "Middle East and Sahara—Technical Comparisons of Oil Potentialities."

Full-day Symposium—

Professor J. G. McG. Bruckshaw—"Geophysics Today."
H. Fanshawe—"Possible Improvements in Drilling."
P. Threadgold—"Advances in Well Logging."
T. R. Shipster—"Partial Removal of H_2S from Crude Oil by Stripping with Natural Gas."

The attendance at evening meetings and at the Symposium was most encouraging, and a similar programme has been arranged for the summer of 1961. The theme of this symposium will be "Why are Oil Reserves Continually Growing?" Evening meetings have been arranged for February and March.

A joint meeting with the Economics and Operations Group was held in November on "Administration and Supply Problems of New Oilfields."

Publications Committee

The forty-sixth volume of the *Journal* was published during the year. The number of pages of transactions was approximately as in previous years. The number of abstracts was somewhat increased, but the number of pages occupied was slightly lower.

A very successful Summer Meeting on "Planning for Productivity in the Oil Industry" was held at Bournemouth in June, and the proceedings of this were published in November.

It has been necessary to publish "Standard Methods" in four parts—Part I of the 19th edition ("Method for Analysis and Testing"), Parts II ("Methods for Rating Fuels") and IV ("Methods for Sampling") have been issued, and Part III ("Engine Tests of Lubricating Oil") is in the hands of the printer.

Two other booklets, namely the revised edition of the Glossary, and a booklet on "Quality Assessment of Petroleum Products" are also in the hands of the printer, and these are expected to be issued early in 1961.

Work on the preparation of the third edition of "Modern Petroleum Technology" is in progress.

The Library has operated very satisfactorily during 1960, and is giving increased service to both members and other inquirers.

Research Committee

The 1960 Annual Report is made under three headings, these being the Hydrocarbon Research Group, Research Group No. 2, and activities which have been or are currently under review.

I. The Hydrocarbon Research Group. The financial support to University projects during the 16th year ended September 1960 amounted to £8228 against an income of £9000 from Members' contributions.

The Spectroscopic Panel, in addition to continuing to support the work at Oxford, Cambridge, and London (King's College) Universities, have extended their activities to take in a project at Swansea College.

With regard to the Mass Spectrometry Panel, arrangements are now well advanced for the holding of the Second Joint Conference with ASTM Committee E 14 on Mass Spectrometry at Oxford in September 1961.

The Hydrocarbon Chemistry Panel, in addition to continuing support to projects at Queen Mary College and Imperial College, has given support to two new projects, one at North Staffordshire University and the other at Glasgow University.

The Gas Chromatography Discussion Group in conjunction with the Society of Analytical Chemistry held a highly successful four day symposium on Gas Chromatography at Edinburgh in June 1960. There were well over 500 delegates, representing no less than

20 countries. Thirty papers were presented, and the discussions on them have already been published.

II. Research Group No. 2. Research Group No. 2. have kept in close touch with the work of the Medical Research Council Sub-Committee on the carcinogenicity of mineral oils work which has continued at Birmingham (Medical School), Exeter (Chemistry Department), and Manchester (Chemical Engineering Department) universities.

A number of other topics concerning carcinogenicity of materials being handled by the industry are under review, and the necessity for revising the original terms of reference of the Committee is being considered.

III. During the year the Research Committee have continued their review of a number of further subjects which have potential for IP sponsorship.

Standardization Committee.

At the beginning of the year, Mr F. L. Garton relinquished his chairmanship on his retirement to live in the U.S.A. His wise direction and consistent interest in standardization matters will always be an inspiration to those who are continuing the work. The reorganization of Standardization Committee, described in the *IP Review* for February 1960, which he put into effect before retiring, has proved most successful and has required no modification. Three of the four parts of " IP Standards " were issued during 1960, Part I—Methods for Analysis and Testing, in March, Part II—Methods for Rating Fuels—Engine Tests, in October and Part IV—Methods for Sampling, in March. Part III which is to deal with methods for assessing the performance of crankcase lubricating oils in engines will be published shortly.

A brochure has been issued giving full details of the organization of Standardization Committee and another, which lays down a standardized format for IP methods, will enable inconsistencies in their presentation to be avoided.

Much careful thought and planning has gone into the organization of a symposium on the engine-testing of crankcase lubricants which is to be held in May 1961. Furthermore, IP representatives have been elected to serve on the Joint British Committee on Electron Microscopy.

Full co-operation has been maintained with the British Standards Institution, and an agreement has been reached with ASTM, regarding the preparation of additional measurement tables based on densities measured at 20° C. It is also of interest to note that of the 135 IP methods, 30 are now technically identical with their ASTM counterparts. As regards general international co-operation on standardization of test methods, consideration is being given to the possibility of widening the scope and effectiveness of this activity.

Council wishes to record its gratitude to the Member Companies for their generous allocation of their technical specialists' time to carry out this important aspect of the work of the Institute.

MEMBERSHIP 1960

	Total 31 Dec. 1959	Changes during 1960						Total 31 Dec. 1960
		New	Transferred to	Resigned	Deceased	Transferred from	+ or −	
Honorary Members	4	—	—	—	—	—	—	4
Honorary Fellows	8	—	1	—	—	—	+ 1	9
Members	668	37	7	25	9	2	+ 8	676
Fellows	819	41	17	15	18	2	+ 23	842
Associate Members	834	48	—	37	7	9	− 5	829
Associate Fellows	1646	146	7	42	4	13	+ 94	1740
Students	52	15	—	10	—	6	− 1	51
Totals	4031	287	32	129	38	32	+120	4151
Member Companies	235	10	—	8	—	—	+ 2	237

DEATHS

G. D. Arden (F)
S. E. Ashman (AM)
G. T. Becker (F)
S. F. Birch (F)
R. J. Bressey (F)
P. R. Clark (F)
G. L. Coles (F)
R. Doumain (AM)
G. W. Dunkley (M)
A. L. Eastlake (AF)
D. T. Germain-Jones (F)
P. H. Gledhill (AM)
P. W. L. Gossling (F)
R. B. Grey (F)
A. C. Hartley (F)
C. D. Hobson (AM)
E. J. Horley (M)
N. A. Kearney (F)
J. W. Kittle (F)
G. W. Knight (M)
Sir George Legh-Jones (F)
H. MacNiven (F)
J. Meikle (AM)
H. C. Moore (AF)
W. H. Niel (M)
C. Nutbeem (AM)
L. Owen (F)
G. M. Park (F)
E. F. Patridge (M)
A. R. Pattisson (M)
A. C. Pepper (M)
H. W. W. Reece (AF)
J. Wardlaw Reid (AM)
C. V. Rutherford (M)
P. M. E. Schmitz (F)
A. J. Stafford (M)
B. A. M. Thomas (AF)
S. J. Vos (M)

A. C. Hartley had served on Council for over ten years and was a vice-president at the time of his death. Mr Hartley was awarded the Redwood Medal in 1959.

E. J. Horley served on Council, as a Branches representative, from 1951 until 1955.

Sir George Legh-Jones was formerly Managing Director of Shell Transport & Trading Co. Ltd. and S. J. Vos was formerly Chairman of Trinidad Leaseholds Co. Ltd.

L. Owen and R. B. Grey had been members of the Institute for 45 years and P. R. Clark for 44 years. P. M. E. Schmitz had been a member for over 38 years and G. W. Dunkley, D. T. Germain-Jones and C. V. Rutherford for over 30 years.

Staff

The staff of the Institute under the guidance of the General Secretary have continued to give a most efficient and loyal service. This year has been rather trying in a number of respects, for we have experienced some difficulties in staff replacement, whilst the volume of work has continued to rise.

During the year a review of salary scales for our clerical staff was carried out, and as a result of this a decision was made to apply certain adjustments to bring them more into line with community practice.

Plans have been made to anticipate Mr George Sell's pending retirement from the post of Editor of the Institute of Petroleum on 31 March 1961. On this date he completes many years of devoted and valued service, having been associated with the Institute of Petroleum since its inception in 1913. We have been fortunate enough to retain his services on a part-time basis for some time to come. Council wishes to record its thanks and deep appreciation of his service.

By Order of the Council,
G. A. Dickins,
Honorary Secretary

1 *March* 1961

THE INSTITUTE OF PETROLEUM

BALANCE SHEET
31 DECEMBER 1960

Together with supporting Accounts at that date and Hydrocarbon Research Group Revenue Account and Statement of Funds as at the 30 September 1960

THE INSTITUTE

(A Company limited by Guarantee

BALANCE SHEET AS

1959 £	£		£	£	£
		Capital of the Institute:			
		Life, Entrance, and Transfer Fees and General Donations—	£		
		As at 31 December 1959	10,932		
10,932		*Add* Receipts during 1960	413		
				11,345	
		Special Donations—Building Fund Account—			
91,010		As at 31 December 1959		91,010	
101,942				102,355	
		Investment Reserve—	£		
		Net Loss on Realization of Investments	264		
		Less Reserve at 31 December 1959	188		
			76		
		Less Transfer from Revenue Account	76		
188				—	
102,130					102,355
		General Reserve:			
20,000		As at 31 December 1959		25,000	
5,000		*Add* Transfer from Revenue Account		—	
25,000					25,000
		Special Reserves:			
1,000		General Repairs and Maintenance		1,500	
—		6th World Petroleum Congress		1,000	
1,000					2,500
		Revenue Account:			
30,082		As at 31 December 1959		19,566	
—		*Add* Surplus for year		2,013	
30,082				21,579	
516		*Less* Deficit for year	—		
—		Transfer to Investment Reserve	76		
5,000		Amount written off Leasehold Premises	5,000		
5,000		Transfer to General Reserve	—		
10,516				5,076	
19,566					16,503
147,696					146,358
		Subscriptions Received in Advance:			
		Members' Subscriptions		1,710	
		Member-Company Subscriptions		707	
5,406		*Journal* Subscriptions		2,619	
					5,036
		Current Liabilities and Provisions:			
350		Provision for Pension		350	
7,921		Sundry Creditors and Accrued Charges		5,202	
804		World Petroleum Congress		659	
876		Fuel Testing Correlation Fund		1,188	
264		Entertainment Account		577	
10,215					7,976
£163,317					£159,370

AUDITORS' REPORT TO THE MEMBERS

We have examined the above Balance Sheet and annexed Revenue Account and report that we have obtained all the In our opinion, proper books of account have been kept by the Institute, so far as appears from our examination of those best of our information and according to the explanations given to us, the accounts give the information required by the affairs at 31 December 1960, and the Revenue Account gives a true and fair view of the revenue for the year ended on that

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
10 *March* 1961.

OF PETROLEUM

and not having a Share Capital)

AT 31 DECEMBER 1960

1959 £	£		£	£
		Leasehold Premises (996 years unexpired):		
	19,999	Cost of acquisition in 1955	19,999	
	90,787	*Add* Cost of conversion	90,787	
	110,786		110,786	
	10,000	*Less* Amounts written off	15,000	
100,786				95,786
		Office and Library Furniture:		
	11,889	At Cost	12,341	
	4,869	*Less* Aggregate Depreciation	7,337	
7,020				5,004
		Investments—at Cost (per Schedule I):		
34,197		(Market Value at 31 December 1960 £41,094; 1959 £37,939)		41,288
		Current Assets:		
	3,240	Stock of Publications as certified by the General Secretary	3,422	
	7,533	Sundry Debtors and Payments in Advance including tax recoverable	8,239	
	—	Members' Subscriptions in arrear—not valued	—	
	32	Member-Company Subscription in arrear	11	
	450	Cash on Deposit with Post Office Savings Bank	461	
		Balance at Bank—		
		520 Deposit Account 20		
		8,939 Current Accounts 4,539		
	9,459		4,559	
	600	Cash in Hand	600	
21,314				17,292

Note: The total of the bank balances held by the Institute's Branches but excluded from the above, as at 31 December 1960 was £1,671 (1959 £1,260).

£163,317	£159,370

OF THE INSTITUTE OF PETROLEUM

information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. books. The Balance Sheet and Revenue Account are in agreement with the books of account. In our opinion, and to the Companies Act, 1948, in the manner required, and the Balance Sheet gives a true and fair view of the state of the Institute's date.

(*Signed*) SMITH & WILLIAMSON,

Chartered Accountants.
Auditors.

THE INSTITUTE

(A Company limited by Guarantee

REVENUE ACCOUNT FOR THE

1959 £	£		£	£
		To **Administrative Expenses:**		
		Staff (Other than Publications)—		
	7,893	Salaries and National Insurance	9,656	
	838	Staff Pension Scheme Contributions	865	
8,731				10,521
		Note: Total Salaries £17,045 (1959 £15,146); Total Pension Contributions £1,234 (1959 £1,662)		
	1,732	Printing and Stationery	1,922	
	1,323	General Postages	1,380	
	535	Telephones, Cables, and Travelling Expenses	557	
	3,590		3,859	
	1,197	*Less* Applicable to Publications—one-third	1,286	
2,393				2,573
	95	Audit Fee	137	
	288	General Expenses	356	
	216	Insurances	199	
	—	List of Members	625	
599				1,317
11,723				14,411
		„ **Establishment Expenses:**		
	558	Rent and Water Rates	558	
	617	Cleaning	517	
	485	Gas and Electricity	527	
	205	Heating	263	
	100	Repairs and Maintenance	198	
	1,965		2,063	
	655	*Less* Applicable to Publications—one-third	688	
1,310				1,375
		„ **Meetings:**		
572		Pre-prints, Reporting, etc.		690
715		„ **Grants to Branches**		709
		„ **Sundries:**		
	307	Library Expenses	651	
	363	Legal Expenses	—	
	112	Subscriptions to Societies	123	
	100	Scholarship Awards	100	
882				874
2,378		„ **Depreciation of Furniture (20%)**		2,468
3,785		„ **5th World Petroleum Congress**		
		„ **Publications:**		
	30,658	Production and Distribution	29,726	
	8,076	Salaries, National Insurance and Pension Scheme Contributions	7,757	
	1,852	Proportion (one-third) of Administrative and Establishment Expenses	1,974	
	£40,586		£39,457	
	20,168	Advertising Revenue	21,091	
	16,910	Sales	16,958	
	£37,078		£38,049	
3,508		Deficit		1,408
24,873				21,935
500		„ **Transfer to Reserve for General Repairs and Maintenance**		500
—		„ **Transfer to Reserve for 6th World Petroleum Congress**		1,000
516 (Deficit)		„ **Balance, being Surplus Revenue for Year**		2,013
£24,857				£25,448

OF PETROLEUM

and not having a Share Capital)

YEAR ENDED 31 DECEMBER 1960

1959		£
13,239	By **Members' Subscriptions received for 1960**	13,634
145	„ **Members' Subscriptions in arrear received during year**	156
10,260	„ **Member-Company Subscriptions received for 1960**	10,272
20	„ **Special Subscription**	20
1,193	„ **Interest and Dividends Received (Gross)**	1,366
£24,857		**£25,448**

HYDROCARBON RESEARCH GROUP

Revenue Account for the Year ended 30 September 1960

	£	£		£
To **Stock in Hand of "Molecular Spectroscopy"**		22	By **Voluntary Contributions from Members of the Group**	9,000
„ **Grants:**			„ **Sales of Molecular Spectroscopy**	35
Imperial College of Science and Technology	267		„ **Balance,** being Deficit for the year	83
Gas Chromatography Discussion Group	50			
King's College	1,362			
Queen Mary College	1,500			
University of Belfast	350			
University of Cambridge	700			
University of Glasgow	1,650			
University of North Stafford	700			
University of Oxford	1,250			
University of Swansea	450			
		8,279		
„ **Honoraria**		420		
„ **Preprints and Reports**		47		
„ **Salaries**		350		
		£9,118		£9,118

Notes:

(i) For convenience in administration, the Accounts of the Group are closed as at 30th September each year.

(ii) The Group are now liable to bear all losses incurred in connection with their publications.

Statement of Funds as at 30 September 1960

	£	£		£
Revenue Account:			**Balance at Bank on Current Account**	2,453
As at 30 September 1959	2,274		*Note:*	
Less Deficit for year	83		The Bank balance of the Gas Chromatography Discussion Group, excluded from the above, as at 30 September 1960 was £295.	
		2,191		
Sundry Creditor—The Institute of Petroleum		262		
		£2,453		£2,453

We have examined the above Revenue Account and Statement of Funds with the books and vouchers of the Group and find them to be in accordance therewith.

Scottish Union House,
25 Bucklersbury,
London, E.C.4.
10 *March* 1961.

(*Signed*) Smith & Williamson,
Chartered Accountants.
Auditors.

CARCINOGENICITY RESEARCH FUND

STATEMENT OF FUNDS AS AT 31 DECEMBER 1960

	£		£
Balance of Sum Received from the Petroleum Board (during 1947)	303	**Balance at Bank on Current Account**	304
Accumulated Net Income:			
As at 31 December 1959	1		
	£304		£304

We have examined the above Statement of Funds with the books and vouchers of the Fund and find it to be in accordance therewith.

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
10 *March* 1961.

(*Signed*) SMITH & WILLIAMSON
Chartered Accountants.
Auditors.

CADMAN MEMORIAL FUND

STATEMENT OF FUNDS AS AT 31 DECEMBER 1960

			£	£
Balance of Fund at 31 December 1959	3,451		**Balance at 31 December 1960:**	
Add Interest Received (Gross)	106		£2,730 3% Savings Bonds 1965/75	2,730
	3,557		£720 4½% Conversion Stock 1964	692
Less Loss on Investment purchased and sold during year	8		(Market Value 31 December 1960 £2,654)	
		3,549	Dividend due by The Institute of Petroleum	13
			Income Tax Recoverable	8
			Balance at Bank on Current Account	106
				3,549
		£3,549		£3,549

We have examined the above Statement of Funds with the books and vouchers of the Fund and find it to be in accordance therewith.

SCOTTISH UNION HOUSE,
25 BUCKLERSBURY,
LONDON, E.C.4.
10 *March* 1961.

(*Signed*) SMITH & WILLIAMSON,
Chartered Accountants.
Auditors.

Schedule I

THE INSTITUTE OF PETROLEUM

Investments—31 December 1960

	At Cost	Market Value 31 December 1960
£5,345 5% Conversion Stock 1971	4,935	4,837
£5,140 4½% Conversion Stock 1964	4,933	5,011
2,000 British Assets Trust Ordinary 5*s*. Shares	1,977	2,400
4,400 Equities Investment Fund for Charities Units	4,556	4,537
£900 Edinburgh Investment Trust Ltd Deferred Stock	1,564	1,665
300 Imperial Chemical Industries Ltd Ordinary £1 Stock Units	1,106	960
1,300 Keystone Investment Trust Ltd Ordinary £1 Stock Units	2,127	2,080
300 Lloyds Bank Ltd £1 Shares	1,121	1,065
£500 London Scottish Investment Trust Ltd Deferred Stock	1,845	1,656
45 Legal & General Assurance Ltd. 5*s*. Shares	1,122	979
2,280 Mercantile Investment & General Trust Ltd Ordinary 5*s*. Shares	2,114	2,337
2,800 Monks Investment Trust Ltd Ordinary 5*s*. Stock Units	1,879	1,750
66 Royal Bank of Canada $10 Shares	2,119	1,683
750 Pentland Investment Trust Ltd Ordinary £1 Stock Units	2,152	2,484
900 Scottish American Investment Co. Ltd "A" Ordinary £1 Shares	4,274	4,219
600 Second Scottish American Trust Co. Ltd. Ordinary £1 Stock Units	1,456	1,275
2,500 Scottish Northern Investment Trust Ltd Ordinary 5*s*. Shares	2,008	2,156
	£41,288	£41,094

THE INSTITUTE OF PETROLEUM

FORTY-EIGHTH ANNUAL GENERAL MEETING

THE Forty-eighth Annual General Meeting of the Institute of Petroleum was held at 61 New Cavendish Street, London, W.1, on 3 May 1961, the chair being taken by the President, Julian M. Leonard.

The notice convening the meeting and the minutes of the previous Annual General Meeting were read. The minutes were confirmed as a correct record and signed.

ELECTION OF OFFICERS FOR THE SESSION 1961–62

President

On the proposal of Sir Stephen Gibson, C.B.E., seconded by G. A. Dickins, the re-election of Julian M. Leonard for a second term of office as President was carried with acclamation.

Members of Council

Seven nominations were made for the seven vacancies for Council and the following members were therefore declared elected: W. S. Ault, F. N. Beaumont, J. M. Dougary, R. H. W. Hamilton, H. Hyams, J. S. Parker, and D. L. Samuel.

Honorary Treasurer

On the proposal of G. A. Dickins, seconded by T. W. Mathias, O. F. Thompson, O.B.E., was unanimously elected as Honorary Treasurer for the session 1961–62.

Honorary Secretary

Dr T. Gaskell proposed, and J. G. Annan seconded, the election of G. A. Dickins as Honorary Secretary for the session. This was carried unanimously.

Honorary Editor

The election of Dr E. B. Evans as Honorary Editor was proposed by W. S. Ault, seconded by M. E. Hubbard, and carried unanimously.

Ex-officio Member of Council

The chairman proposed that Dr W. B. Peutherer should fill the vacancy as branches representative caused by the resignation of C. W. Banyard. This was seconded and carried unanimously.

MEMBERS ELECTED OR TRANSFERRED

In accordance with the By-Laws, a list of all persons elected or transferred during the year 1960 was tabled.

REPORT OF COUNCIL

G. A. Dickins, presenting the Report of the Council for the year 1960, said: I will just review one or two major items. In the first place, you will be gratified to see that membership still increases; in the last year round about 3 per cent. Activities, branches, committees, and groups continue to increase. Whilst I know it is conventional not to single out any items here, I think I must make mention of the Publications Committee. They have introduced a number of very efficient standard methods, and other publications, during the year. The Engineering Committee's work in revising the various safety codes has established them with a reputation as an authority on these subjects.

In addition to the General Meetings, there have been two other meetings, the Summer Meeting at Bournemouth, which was a great success, and the Gas Chromatography Discussion Group attracted some 500 people, from far and wide, to Edinburgh last year. It was international in every respect.

I must conclude by saying that all these increases in membership, activities, and so on were not done without the devotion of the Institute staff, under the direction of the General Secretary. They have carried out the work over the year with no increase of staff and, indeed, no increase of staff over a number of years. We have revised salary rates over the past year. I am sure you will agree that such rates should at all times be deserving of a small but high quality staff.

The adoption of the report was then seconded by M. E. Hubbard and carried unanimously.

ACCOUNTS

O. F. Thompson, presenting the Accounts for 1960. There are one or two points which might be mentioned, the more interesting part of the Accounts being the Revenue Account. I would draw your attention to the fact, first, that administrative expenses have increased during the year, with total staff expenses running at £17,045 a year, as compared with £15,146 the previous year. The total of other administrative expenses kept fairly closely to the 1959 figures, being about £1200. On the other side of the balance sheet, subscriptions and income give us a total of £25,448, which shows a slight increase over the previous year.

Then we come to the all important point of a deficit or surplus balance, and I am happy to report that we show a surplus revenue for the year of approximately £2000, instead of the deficit for last year. That is after putting aside £1000 against the contingency of possible expenses in the 6th World Petroleum Congress which lies ahead.

All in all, the balance sheet shows quite a satisfactory position. One point on our investments, which cost £41,000 approximately; market value at the end of the year was £41,000, but to-day's value, I am glad to say, is appreciably above that figure.

There is one thing I would I would like to mention and that is that in the coming year we are undoubtedly going to be faced with higher administration expenses, with increasing salaries and so forth; and against that I would urge that we should not rest content with an annual increase in our membership of around 3 per cent. You may agree that there are a large number of people in the industry who will, I am sure, be acceptable to the Membership Committee if they were put up for membership, and I think we ought to bear in mind the possibility of stimulating our new entry.

Mr Thompson then proposed the adoption of the Accounts for the year 1960, which was seconded by W. E. Madden and carried unanimously.

AUDITORS

On the proposal of the chairman, seconded by T. W. Mathias, Messrs Smith and Williamson were re-appointed auditors at a remuneration to be fixed by Council.

OBITUARY

JAMES ALEXANDER JAMESON, C.B.E.

1885–1961

With the passing of J. A. Jameson the army of petroleum technicians loses one of its generals of division and one, moreover, who was one of its most notable pioneers. In the long span of his lifetime, he saw and participated in the remarkable developments of a tremendous industrial revolution, for at the beginning, mineral oil merely provided a cheap and effective illuminant, and at the end a multiplicity of derivatives—specialized fuels, lubricants and detergents, intermediates and solvents.

His birth coincided with that of the Burmah Oil Company, soon about to fill the lamps of India and China.

He was educated at Allan Glen's School, and later proceeded to the Royal Technical College, Glasgow. He served his apprenticeship with the shipbuilding firm of D. and W. Henderson, and then entered the Clydesdale iron and steel works of Stewart and Lloyd.

This company supplied pipe, and was teamed up with Weir's, who made pumps, and so, in 1909, he joined the then Anglo-Persian Oil Company as assistant to Mr Ritchie, who was to be responsible for the first great pipeline connecting the oilfield of Masjid-i-Suleiman with the new refinery at Abadan. Although short by modern standards, a mere 150 miles in length, it had to pass a difficult terrain and traverse two mountain ridges.

Although Jameson's first contract was for one year, it is of interest to know that he stayed on for the long spell of 18 years. He was 24 years of age when he arrived in Persia, and immediately took part in surveying the route of the line. The difficulties were immense, manpower and mule power the only resources, but with indomitable pluck and boundless energy the work was completed by the middle of 1911, when Ritchie pronounced the line to be "bottle tight," and it handled 400,000 tons of oil a year. Now, new lines and boosting stations have to deal with 30 million tons in that period. Jameson lived to see this miracle which was based on his own toil and sweat.

Such a man as Jameson could not be held back, and by 1923 he assumed complete charge of operations in fields, pipelines, and refineries.

In 1927 he was called to headquarters in London, and became General Manager of Production, and Deputy Director. In this year he was honoured by the award of the C.B.E. This was the culmination of his magnificent work in Persia.

In 1935 he was further honoured by being created Officer of the Legion of Honour, in recognition of the great part he had played in the building of the pipelines which connected the Iraq field at Kirkuk with the Mediterranean coast.

In 1937 he was elected to the board of the Anglo-Iranian Oil Company—a most fitting climax to a long career of selfless service to a famous corporation.

During the second world war he rendered yeoman service to the War Office and the Petroleum Department, where his long experience and deep knowledge of petroleum technology was of the utmost value.

As a boy Jameson had a strict Presbyterian upbringing, certain marks of which he carried with him throughout his whole life. As he grew up he was described as "a very serious young man," who would one day go a long way in his chosen career.

I first met J.J. in 1916 on my first visit to Persia—a year before the foundation of the Company's Research Station at Sunbury. He was, as I remember him, particularly sturdy and solid looking, broad and of medium height, fresh complexioned, and always happy and humorous. He was obviously a man of good metal; a favourite expression was "I don't know a word about it," when some technical topic cropped up, and then he at once proceeded to display an intimate knowledge of the matter, accompanied by his friendly and sometimes sardonic smile.

On a later visit in 1924, I saw J.J. very firmly established as General Manager. He had acquired a superlatively excellent staff, and I well remember the

lively discussions at and after dinner in the Big Bungalow. The three men most closely associated with him in those stirring times of rapid development were E. H. O. Elkington, N. Gass, and H. Y. V. Jackson.

But it should never be forgotten that at the back of the new General Manager was a hard core of veteran pioneers who, like himself on the pipeline, had struggled with adversity and won out. I cannot refrain from mentioning his old friend R. R. Davidson, who in 1909 had landed on the desert island where is now one of the world's greatest refineries.

Later visits saw new executives in power, but to my mind the golden epoch was that of Jameson.

The man himself was electric in energy, he was downright, upright, and forthright. We, who knew him, loved him, admired him, and occasionally fought him. His passing has left not a few of us disconsolate.

A. E. D.

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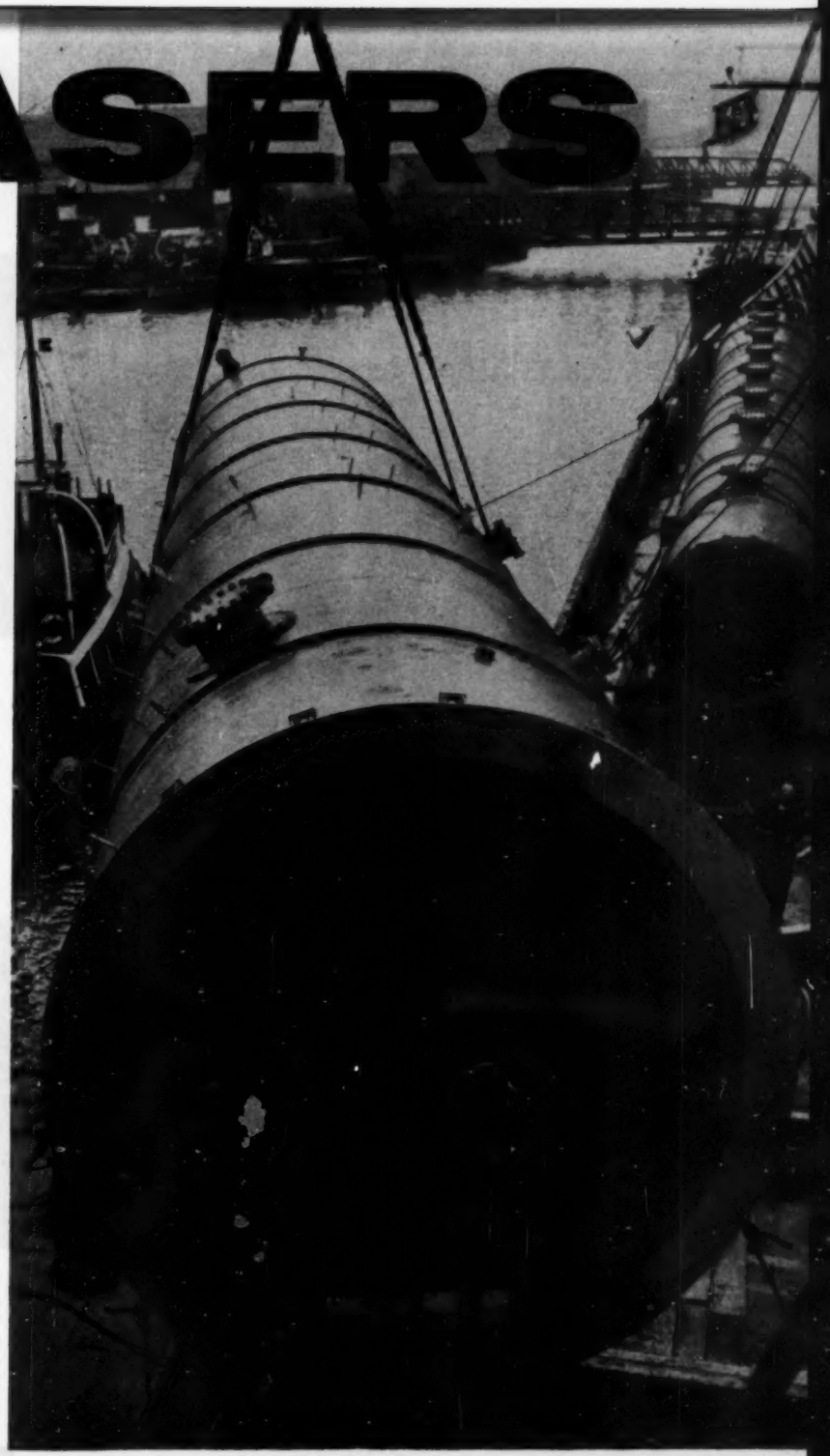

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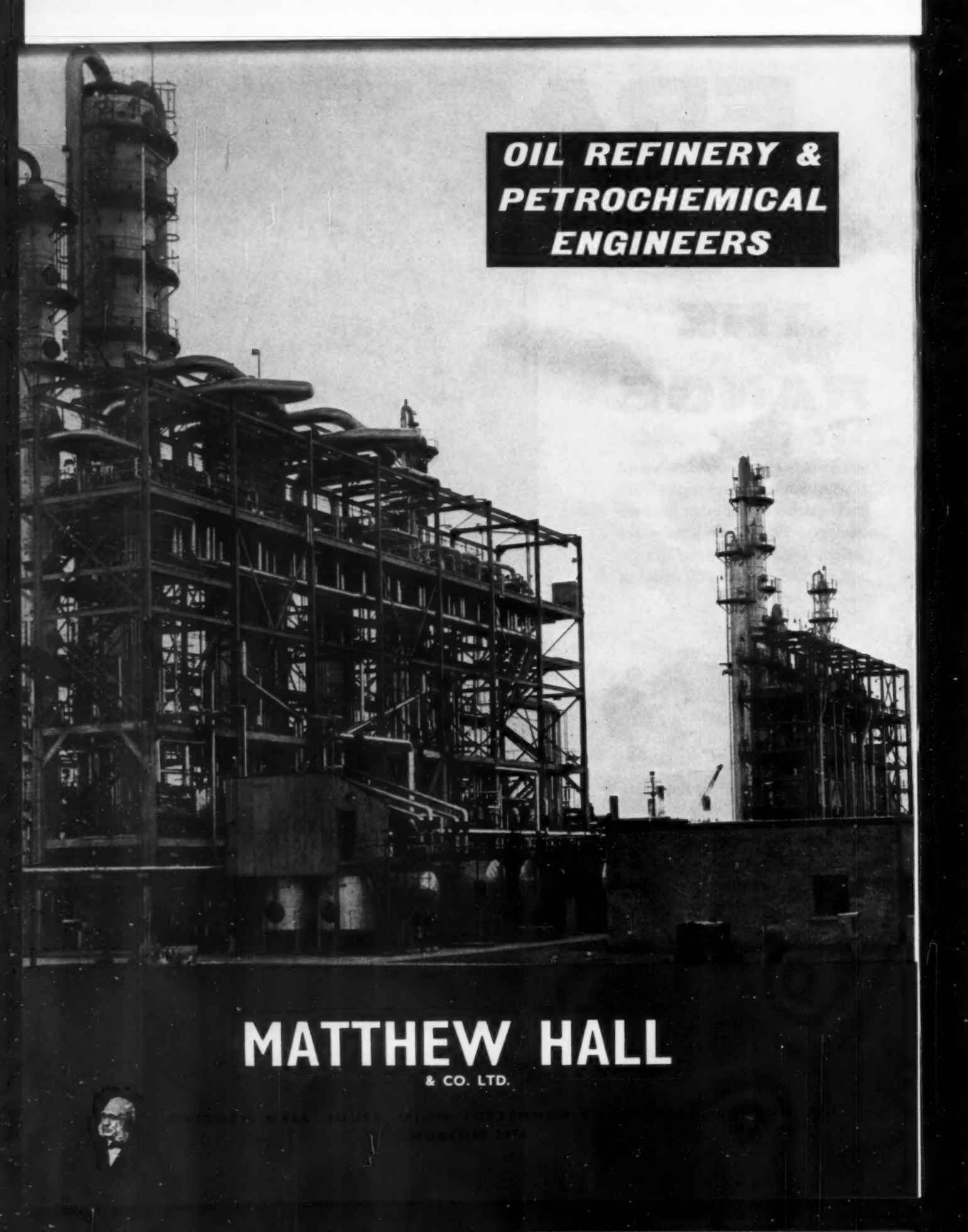
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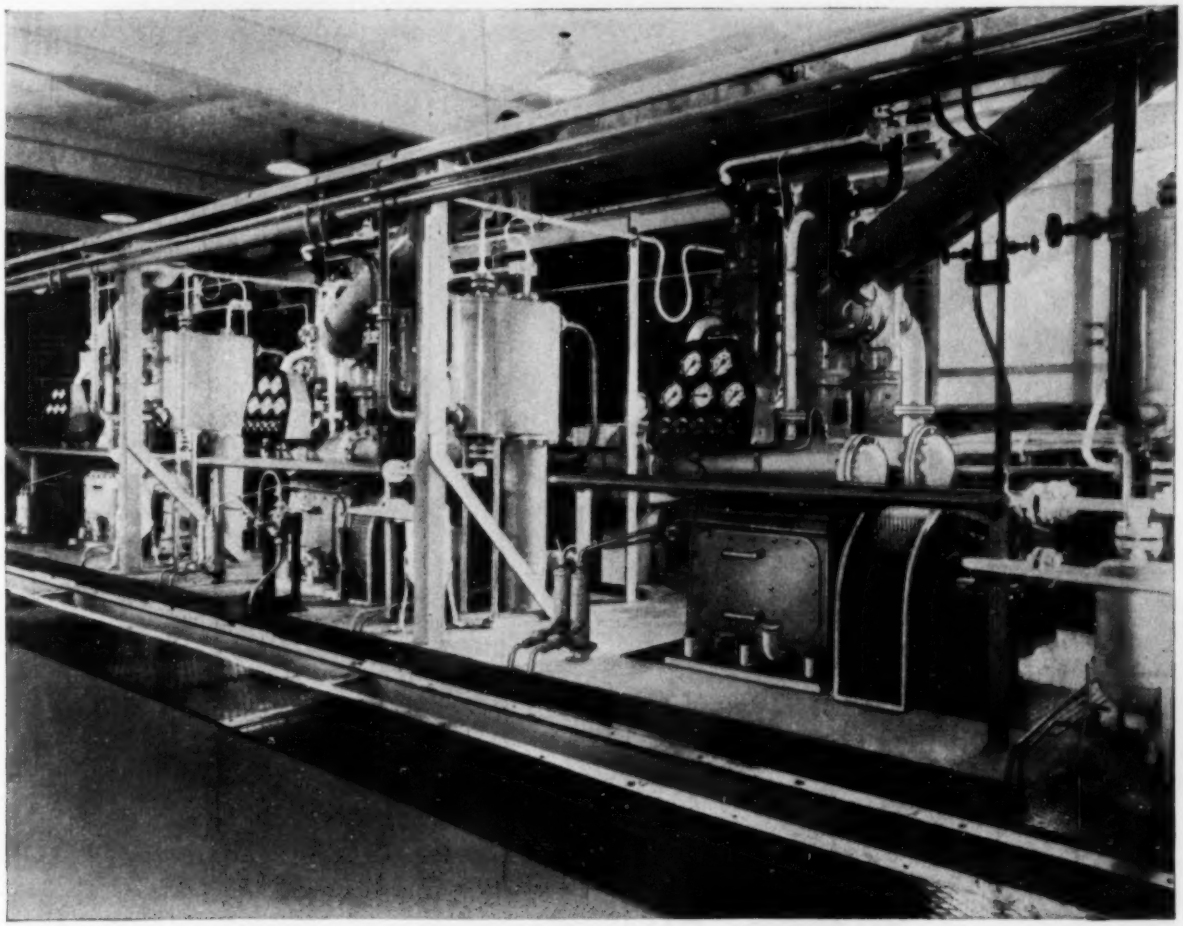

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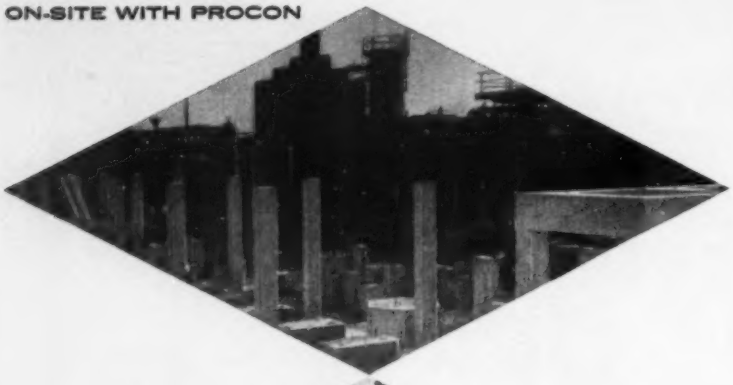

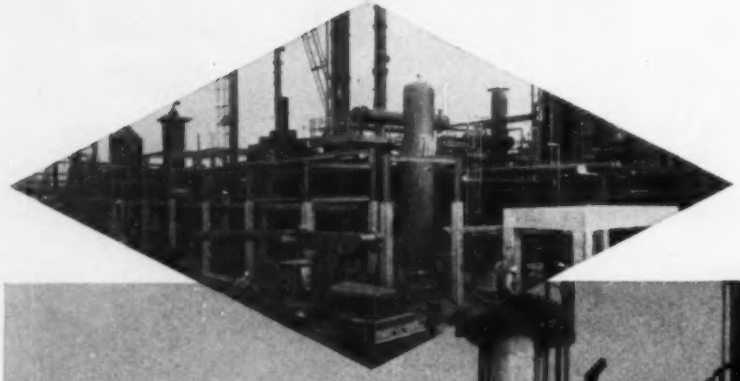

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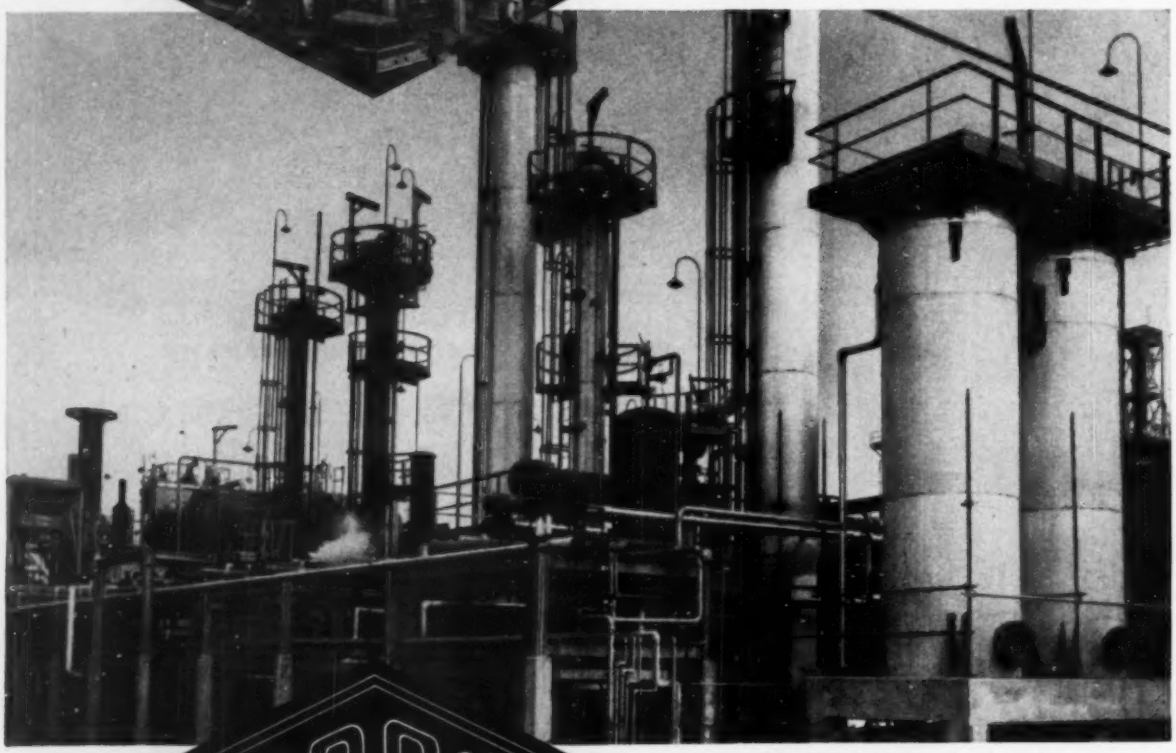

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The previous record for a 10,000-foot well in this area was made with Hughes OSC-3J's. We don't pretend that the penetration rate or footage drilled in the record well is par for the OSC-3AJ. But one thing this record does prove is the outstanding performance built into the bit.

The Hughes OSC-3AJ was originally designed for "top hole" digging. But its exceptional performance in low-strength, high-drillability formations and its availability in a wider range of sizes is extending its use to greater depths and in an increasing number of areas of the world.

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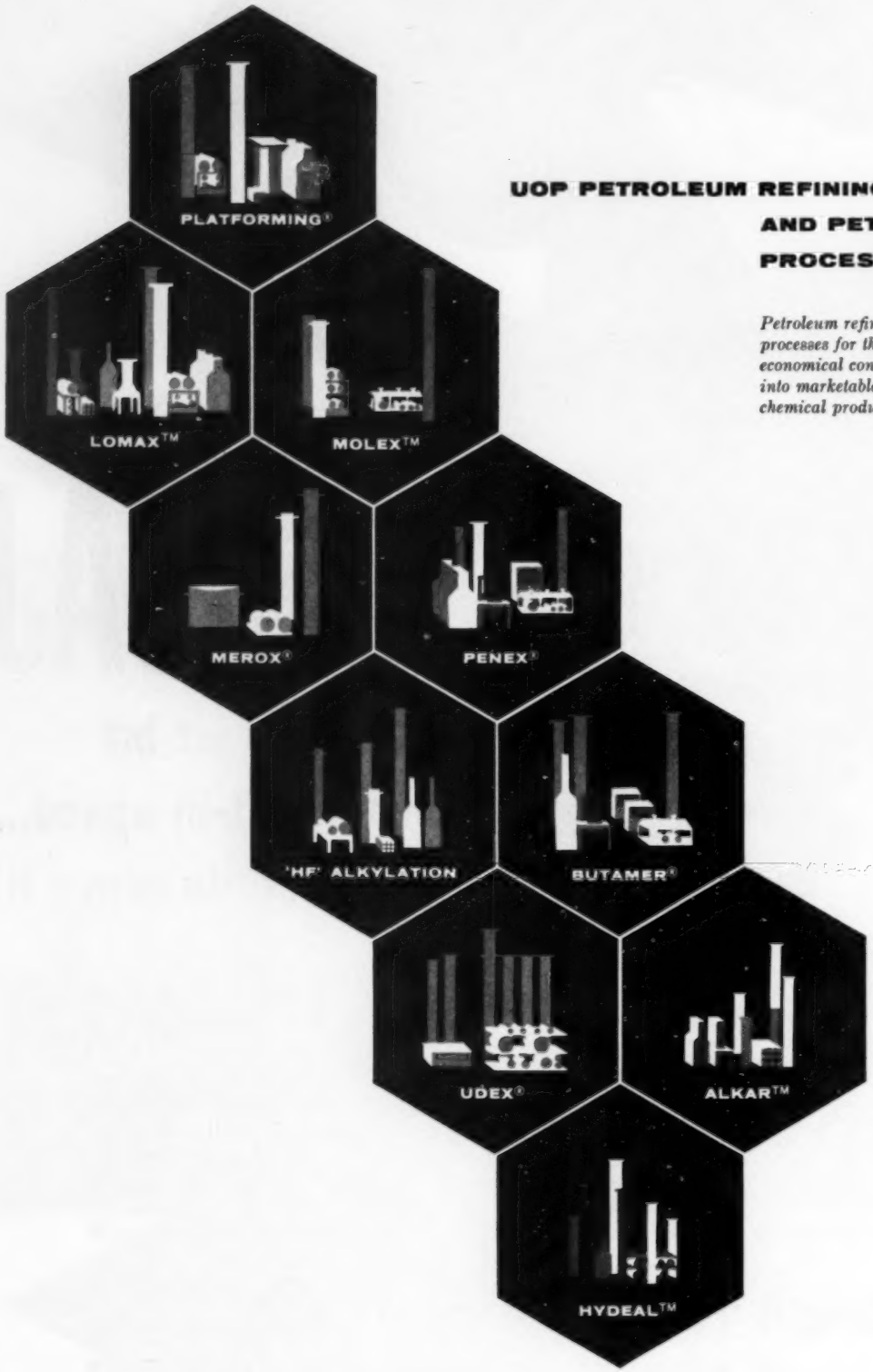

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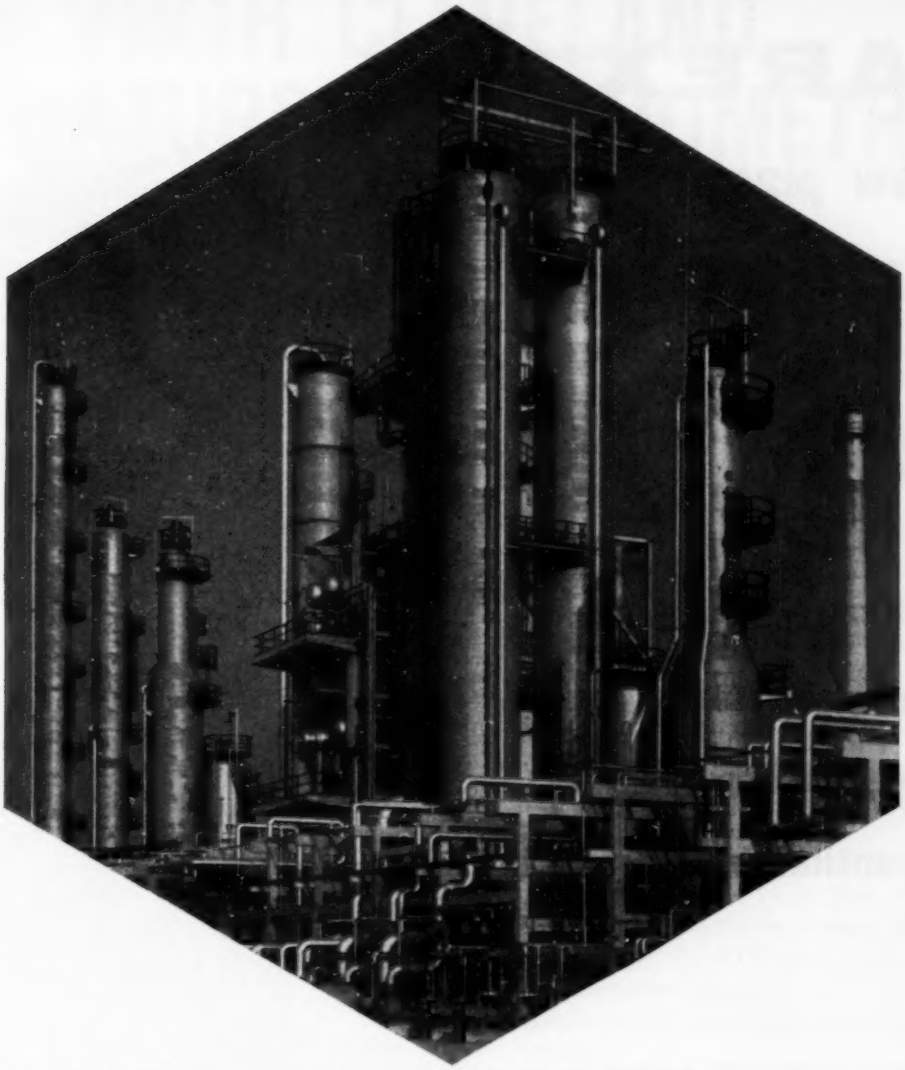

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Udex has operational flexibilities too. Feed to a Udex unit can vary widely in both quantity and composition, yet the stringent specifications of the product output will be maintained. Originated by Dow Chemical Company, the Udex extraction process was developed and is made commercially available by UOP.

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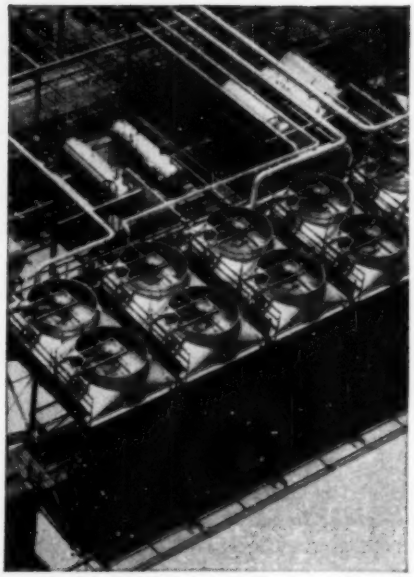
and ventilation



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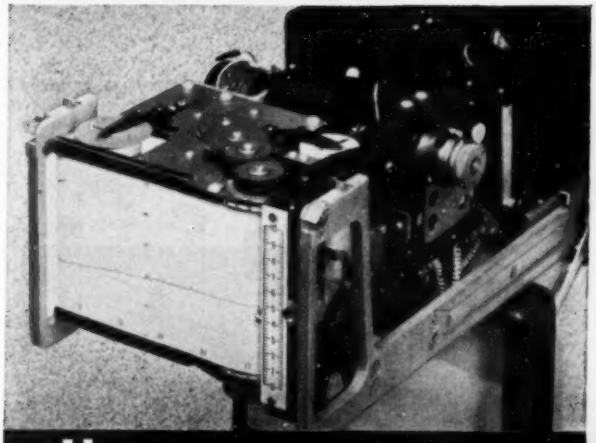
greater safety-easy installation-minimum maintenance.

Enquiries to

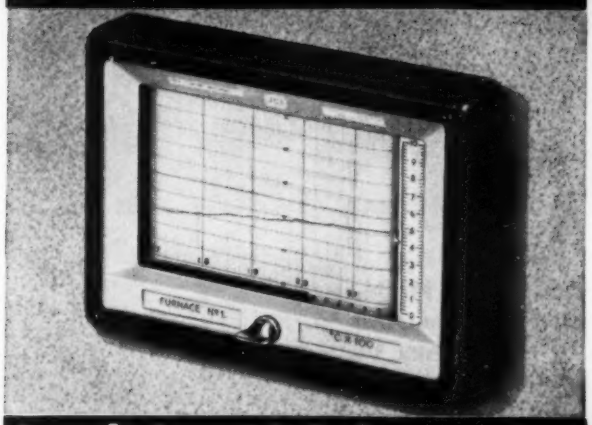
MARSTON EXCELSIOR LIMITED
(A subsidiary company of Imperial Chemical Industries Limited.)
Fordhouses, Wolverhampton.

MAR 274

THE FIRTH CLEVELAND MINIATURE POTENTIOMETRIC RECORDER



all this instrument



behind this $7\frac{7}{8}$" x $5\frac{1}{2}$" front cover

The Firth Cleveland Miniature Potentiometric Pen Recorder packs all the features you normally find behind a 12 inch wide chart—including control facilities—into the smallest possible space.

Here is a brief list of the main points:

(1) Entirely self-contained.

(2) Zero Suppression facilities.

(3) Limit and Deviation Switches can be fitted as optional extras.

(4) Facilities are available in the form of output shaft to operate a pneumatic or electronic controller.

Overall Dimensions: Front panel space $7\frac{7}{8}$" wide x $5\frac{1}{2}$" high. Overall length $18\frac{1}{4}$".

Chart and Scale: 3 inch calibrated width.

Chart Speeds: $\frac{1}{2}$, 1, 2, 3, 6 and 12 inches per hour according to gears fitted.

Chart Life: 1 month at 1 inch per hour.

Range Sensitivity: 1, 5, 10, 20, 50 or 100 millivolts for full span according to range unit fitted.

Accuracy: $\pm 0.5\%$ of full span or ± 10 microvolts whichever is greater.

Sensitivity: 0.1% or 5 microvolts whichever is greater.

Stability: Within 0.3%, except for 1 millivolt range where it is within 0.5%.

Pen Speed: 1 second across 3 inch chart.

Voltage Reference: Zener Diode Source having a stability within $\pm 0.025\%$. No standard cell required.

Power Supplies: 200-250v. A.C. 50 C.P.S. Supply variations up to $\pm$ 10% have a negligible effect upon the accuracy of recording.

Let us send you information about the instrument—and how to adapt it to your particular needs.

FIRTH CLEVELAND INSTRUMENTS LTD.

7, Cleveland Row, London, S.W.1

Telephone: WHItehall 3100

BRANCHES: BIRMINGHAM · MANCHESTER · GLASGOW · STOCKHOLM COPENHAGEN · BALLARAT · SYDNEY · JOHANNESBURG NAARDEN · MILAN · NEW YORK · BRUSSELS · MANNHEIM

A MEMBER OF THE FIRTH CLEVELAND GROUP

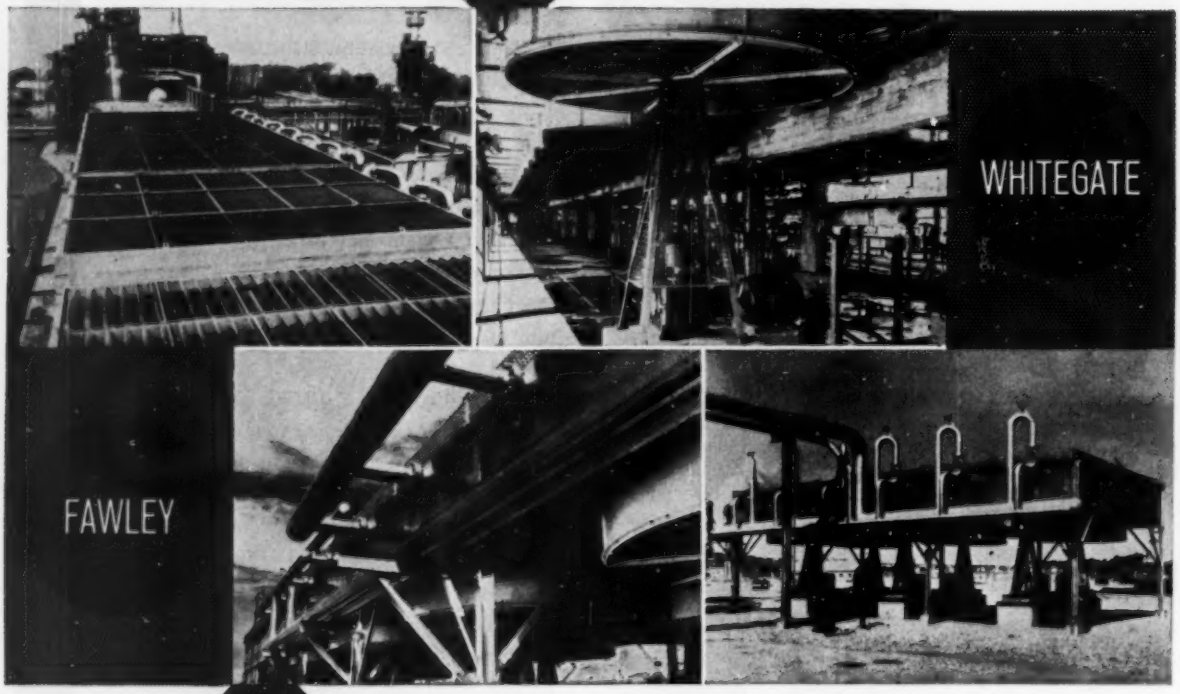
CRC 346

CRAIG

Solo-aire

HUDSON

(Air Cooled Heat Exchangers)
AS INSTALLED IN FAWLEY AND WHITEGATE REFINERIES



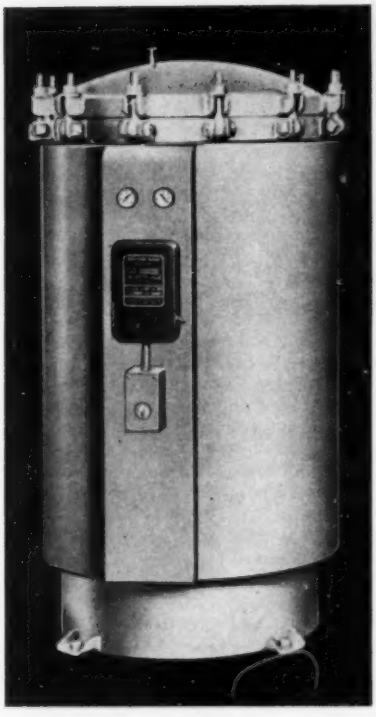
'SOLO-AIRE' Exchangers are part of the range of air cooled equipment for which A. F. CRAIG & CO. LTD. of Paisley, Scotland, are licensed by the HUDSON ENGINEERING CORPORATION of Houston, Texas, U.S.A., to manufacture for sale throughout the world.

ENQUIRIES :—
A. F. Craig & Co. Ltd., Caledonia Engineering Works, Paisley, Scotland
Tel: Paisley 2191

LONDON :—
727 Salisbury House, London Wall, E.C.2.,
Tel: NATional 3964

Let's tell 'em

about the 'C' Type filter Mr B



don't forget the heaters Mr D

"The 'C' Type Birfield-Hilco oil filter", answers Les Brown, "is designed for high flow rate filtration for virtually all forms of oils, whether for small stationery diesel engines or for giant rolling mills."

On the question of heaters for filtration, Dave Davies advises: "Filters without heaters (Models FC and HFC) are ideal for solvents, fuel oils or lube oil which can be delivered to the filter at viscosities up to 300 Redwood No. 1 or a minimum temperature of 120°F. With heavy oil below 120°F. it is wise to use filters with heaters, particularly where the oil viscosity is above 260 Redwood No. 1."

Les Brown and Dave Davies head the only British oil filtration advisory service of its kind —contact them personally . . . ring MIDland 7961 today!

BIRFIELD-HILCO

OIL FILTRATION AND RECLAMATION EQUIPMENT

MEMBER OF THE BIRFIELD GROUP

Manufactured by

INTERMIT LIMITED

"The Hilliard Corporation" licensees

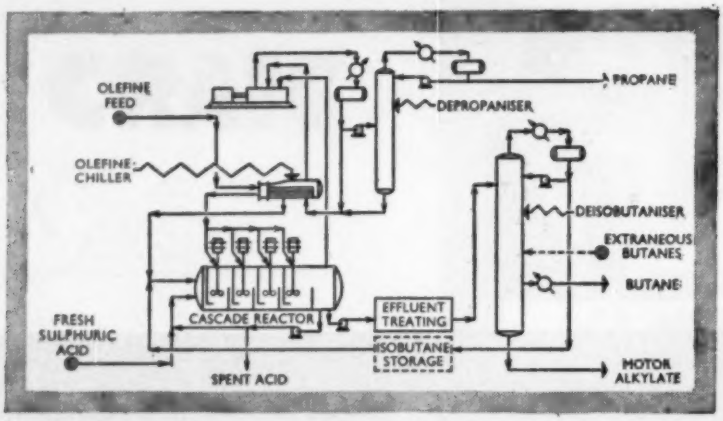
BRADFORD STREET • BIRMINGHAM 5

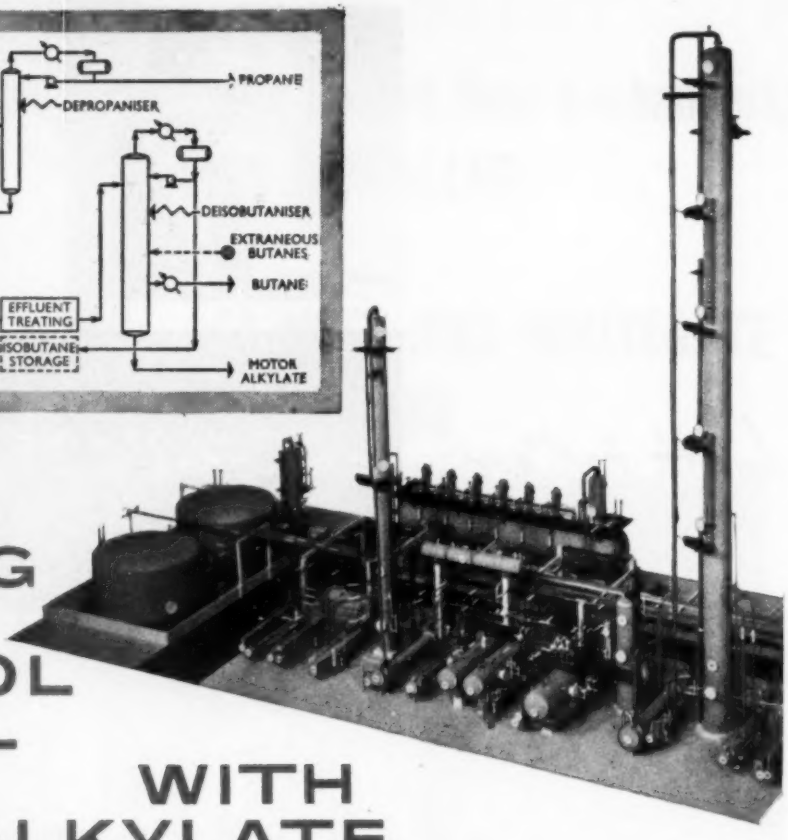
'C' SERIES FILTERS

'B' SERIES FILTERS

DUPLEX FILTERS

000 SERIES FILTERS





PRIMING THE PETROL POOL WITH ALKYLATE

More and more motorcars—and engines with higher compression ratios—these are creating a demand for higher octanes and for a higher quality petrol pool blend.

Both can be achieved, at a lower overall expenditure than ever before, by adding a Kellogg sulfuric acid alkylation unit to your plant. Designed to operate on butylene, propylene, amylene or a combination feed, these units offer many advantages over other designs. The most efficient, most economical and most flexible is the latest multi-stage cascade reactor design shown and described in brief right. It can produce an LPG product, without supplementary towers or equipment. It reduces corrosion to a minimum without extensive use of expensive chemicals. It uses less than 0.35 pounds sulfuric acid per gallon of butylene alkylate produced. It is adaptable to seasonal demands—capable of maintaining peak barrel octane production at minimum operating cost. It can produce specification butane without the addition of a debutanizer tower. These and other features are the result of improvements made through continuing development work, and of Kellogg's world-wide experience in alkylation. To date, Kellogg has designed, constructed or is working on 38 units in 7 countries with a total production capacity of over 141,000 BPD.

Kellogg International Corporation welcomes the opportunity of discussing alkylation in further detail with interested refinery engineers.

Process Description

The olefine feed is chilled and split into parallel streams and fed to separate reaction zones in the Cascade Reactor. Vaporization in each zone removes the heat of reaction and economically maintains low temperatures by auto-refrigeration. Condensed refrigerant is depropanized and mixed with recycle isobutane and acid catalyst. This mixture flows in series through the reaction zones. The effect is of many reactors, each receiving the total recycle plus refrigerant isobutane (used to aid the reaction and to provide refrigeration).

Reactor effluent containing reaction products, recycle isobutane and inert components, is separated from the acid catalyst in the reactor's settling zone, treated to remove entrained acidic material and fractionated to separate isobutane recycle, butane and motor alkylate. Total alkylate product can be added directly to petrol pool or rerun for use in aviation petrol.

KELLOGG

Kellogg International Corporation

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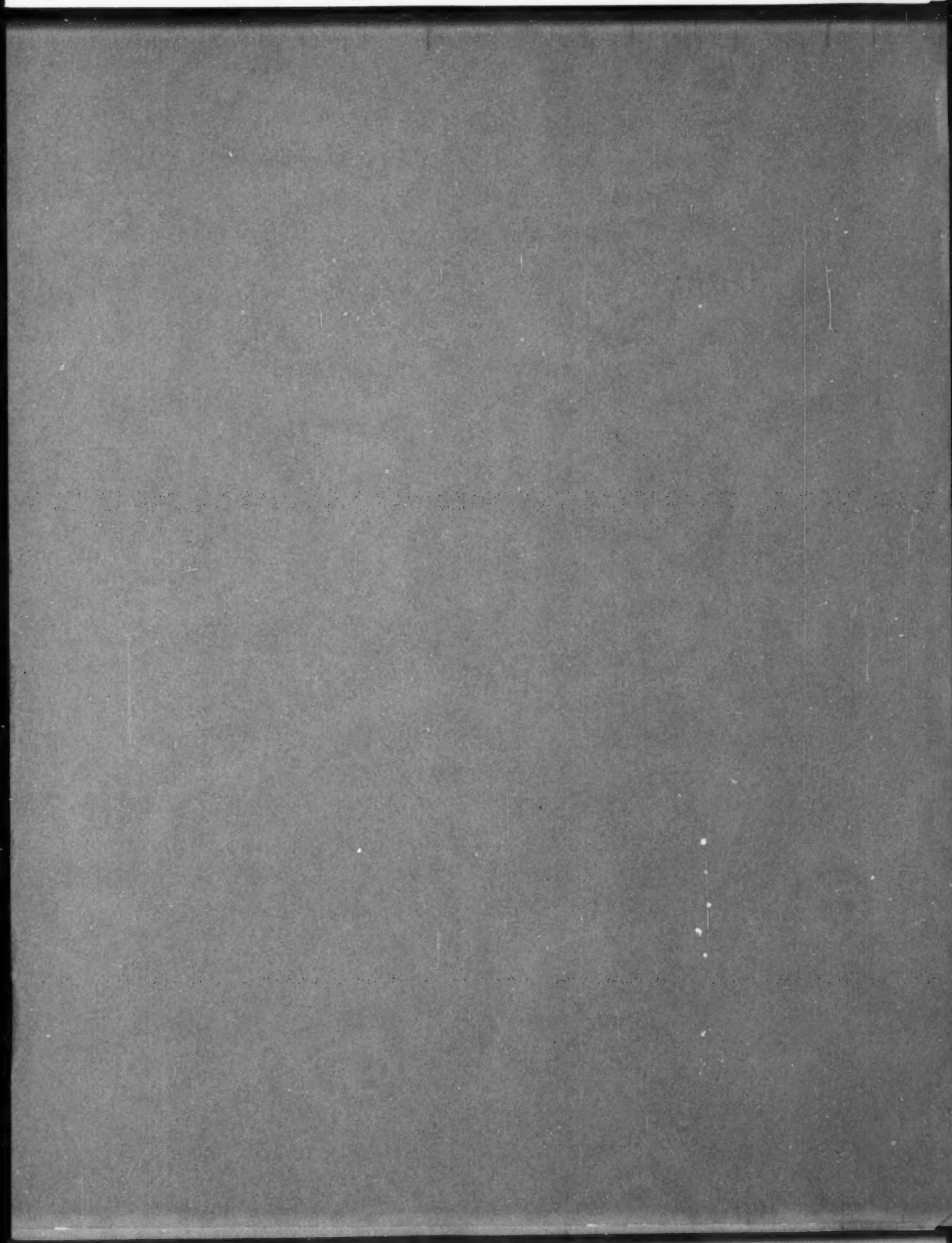
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